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FORECASTING 700-MB. DEWPOINT DEPRESSION BY A 3-DIMENSIONAL TRAJECTORY TECHNIQUE

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ABSTRACT

Quasi 3-dimensional forecasts of 700-mb. dewpoint depression are made for periods up to 36 hours using observed 700-mb. charts and initial and 12-hr. forecast vertical motion charts from the JNWP Unit's "thermotropic model." Results show that moisture can be successfully forecast by this technique. Through establishment of a relationship between 700-mb. dewpoint depression, instantaneous vertical velocity, and large-scale weather, a forecast scheme is devised using forecast 700-mb. dewpoint depression and forecast vertical motion from the thermotropic model as arguments. Preliminary results of some experimental forecasts are favorable.

1. INTRODUCTION

This investigation was undertaken to determine how accurately moisture could be forecast using a quasi 3-dimensional trajectory technique. The moisture parameter selected was the 700-mb. dewpoint depression (T_d). This parameter is not dependent on total moisture and is considered to be a representative measure of the degree of saturation in that region of the atmosphere most associated with clouds and precipitation. The dewpoint depression of a parcel of air is assumed to change in a dry adiabatic process as a result of the vertical motions of the air parcel. The components chosen for the 3-dimensional trajectory were the 700-mb. wind, representing the mean isobaric component, and the vertical motion w produced by the Joint Numerical Weather Prediction (JNWP) Unit's "thermotropic model" [1], as representative of the mean vertical component. Forecasts were made for periods of 12, 24, and 36 hours from a 1500 GMT starting time.

In order to minimize forecast error, observed 700-mb. charts and initial and 12-hr. forecast w charts were used. The appropriate 700-mb. charts were used as perfect 12, 24, and 36-hr. forecasts. The initial (i. e., observed) w charts (1500 GMT) were used for initial and +24-hr. times in the trajectory computations. The 12-hr. w forecasts were used for +12 and +36-hr. times.

Briefly, the method consists of computing trajectories backward from forecast point to initial point, using the forecast 700-mb. charts in descending time order, to arrive finally at the initial chart. Hence a point is determined on the initial chart that will reach the station in the forecast time (12, 24, or 36 hours). The appropriate vertical motion is summed up over the route of the trajectory and applied to the initial dewpoint depression to get a forecast depression.

One hundred 12-, 24-, and 36-hr. forecasts of dewpoint spread were made using the 3-dimensional technique. Also, in order to have some measure of skill, forecasts were made from the same data using (1) persistence, and (2) 2-dimensional trajectories. In the former the initial dewpoint spread is presumed to hold for the entire forecast period (up to 36 hours). The latter technique is similar to the quasi 3-dimensional technique, except that the

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vertical motion component is omitted. Linear correlations between forecast and observed values for all three methods were obtained.

Finally a relationship was established between observed values of 700-mb. dewpoint depression, vertical motion, and the actual weather which serves as the basis of a forecast scheme. By plotting forecast values of T_d and w against time, a continuous forecast of large-scale cloudiness and precipitation (up to +36 hours with the thermotropic model) can be obtained.

2. PROCEDURE

Five stations were selected as forecast points; viz., Oklahoma City, Okla., Omaha, Nebr., Nashville, Tenn., Dayton, Ohio, and Washington, D. C. Forecasts of 700-mb. dewpoint spread were made for these stations for 12, 24, and 36 hours for 20 consecutive days from October 17 to November 5, 1956. Initial time was 1500 GMT.

In the trajectory computations, observed geostrophic winds were used throughout. By way of example, the procedure for construction of a 36-hr. trajectory is outlined: The trajectory is started on the +36-hr. 700-mb. "forecast" chart, by moving backward from forecast point. The +30-hr. point is transferred to the +24-hr. 700-mb. chart and the trajectory continued for 12 more hours to obtain the +24- and +18-hr. points. Pattern movement is closely considered since we are dealing with a 12-hr. trajectory segment using one chart. Next the +18-hr. point is transferred to the +12-hr. 700-mb. chart. Reverse motion is continued for two more 6-hr. periods, producing the +12- and +6-hr. points. Pattern movement is again considered. The +6-hr. point is transferred to the initial or 0-hr. 700-mb. chart and the final 6-hr. reverse motion accomplished. This produces the location of the intitial point. Air at this point can be expected to reach the forecast point in 36 hours.

The dewpoint spread at the initial point is determined by interpolation from a carefully performed dewpoint spread analysis. The effects of vertical motion on this dewpoint spread are now determined by first summing up the vertical motion components from the 12-hr. interval w charts. This is done by adding (1) w at forecast point on the +36-hr. chart; (2) $2w$ at +24-hr. point on +24-hr. w chart; (3) $2w$ at +12-hr. point on +12-hr. chart; and (4) w at initial point on the initial w chart. Doubling of w on the +24- and +12-hr. charts is due to the fact that these charts represent two 6-hr. advection periods. We now have a total of six 6-hr. w components. These are added and the total divided by 36 to get the net w effect per hour. This amount of vertical motion acting for 36 hours will then change the dewpoint spread a certain amount. The spread will decrease with positive vertical motion, increase with negative vertical motion. The relation between change in dewpoint depression and vertical motion in the vicinity of the 700-mb. level was determined from a skew T–log p adiabatic diagram. A scale was drawn up which conveniently gives the change in T_d due to vertical motions acting for periods of 12, 24, and 36 hours.

TABLE 1.—*Linear correlation between forecast and observed 700-mb. dewpoint depression. F_p=persistence forecast, F_2=2-dimensional forecast, and F_3=quasi 3-dimensional forecast*

	F_p	F_2	F_3
r (12 hr.)	0.60	0.64	0.77
r (24 hr.)	.31	.42	.73
r (36 hr.)	.07	.23	.56

The 24- and 12-hr. trajectories were done analogously to the 36-hr. ones but were correspondingly simpler.

The vertical motion from the thermotropic w charts was used without alteration in the initial 3-dimensional computations. This theoretically applies at 500 mb. However, in view of the assumptions in thermotropic theory [2] and the approximate trajectory and vertical motion summation technique, it was decided at first that little if any benefit could be gained by reducing the thermotropic w to 700 mb. Later the 24-hr. forecasts were recomputed using a 700-mb. w obtained from the 500-mb. w by assuming a parabolic distribution of vertical motion with height.[2]

One other procedural point of interest is the limit placed on the 700-mb. dewpoint depression. This was arbitrarily set at 15° C. and applies to both initial and forecast values. The reason for this is that when the depression ranges up near 15°, a missing (or "motor-boating") dewpoint is usually reported. At the other end of the range, the lowest dewpoint spread was zero. Values calculated to be negative were considered to be zero.

3. RESULTS

The results are best shown by means of the correlation table (table 1). Recall that these results were obtained using observed 700-mb. charts and observed and 12-hr. forecast w charts. Thus they represent something near the upper limit of proficiency for the manual 6-hr. step trajectory technique. All forecast spreads were verified by 700-mb. observed spreads, with the arbitrary 15° C. limit applied.

Table 1 shows the distinct advantage in using the vertical motion. The correlation for 24-hr. forecast using 700-mb. w was 0.71, which is not significantly different from that obtained using 500-mb. w.

One other correlation was computed, suggested by the work of Hertzberg [2]. Hertzberg developed a rain or no-rain forecast technique for Washington, D. C., which consists of applying the JNWP Unit's forecast vertical

[2] Note on thermotropic vertical motion: Thermotropic theory [1] assumes a vertical motion distribution where the vertical mass transport (ρgw) is 0 at the top of the atmosphere and over flat terrain and is a maximum at the level of nondivergence, taken to be about 500 mb. Terrain-induced vertical motion is included but the effect is damped out above the terrain. Vertical motion for a level different from 500 mb. can be computed by assuming a parabolic profile, with the vertical mass transport 0 at 200 mb. and sea level, and with a maximum at about 500 mb. Using 200 mb. as a zero level permits the use of a linear height axis. Thus the zero levels are at 0 ft. and about 38,000 ft., the maximum ρgw level about 19,000 ft. Such a relation was worked out and scales drawn up to give vertical motion at any level in terms of thermotropic 500-mb. w.

motion (up to 36 hours) to the most moist 150-mb. layer of the current (corresponding to numerical forecast initial time) Washington, D. C., sounding. By means of graphs statistically determined, a rain or no-rain forecast is obtained. For purposes of comparison an adaptation of this technique was made by taking the initial dewpoint spread at forecast point and applying the forecast vertical motion to it. The resulting correlation between forecast and observed was 0.54. This compares with 0.42 for a 2-dimensional forecast and 0.75 for the 3-dimensional forecast.

4. OPERATIONAL FORECAST SCHEME

A preliminary relationship between 700-mb. T_s, w, and weather was established by plotting about 250 observed values of 700-mb. T_s (0300 and 1500 GMT), w, and corresponding observed weather. These data were obtained primarily from the trajectory study. The weather was broken down into four categories; viz, (1) precipitation, excluding scattered showers and stratus drizzle; (2) broken to overcast middle and low clouds, excluding fog and stratus; (3) scattered middle and low clouds, with same exclusions as (2); (4) high clouds or clear.

The relationship between the variables showed reasonable correlation, but due to the smallness of the sample some subjective smoothing was necessary to produce isolines delineating the weather categories. The resulting nomogram is shown in figure 1. The nomogram is entered with forecast 700-mb. dewpoint depression (T_s) and forecast vertical motion. The weather at their intersection is determined by the envelopes. In principle, a forecast of large-scale cloudiness and precipitation can be obtained for any combination of forecast T_s and w. On this basis a forecast scheme was devised using JNWP Unit's thermotropic forecast charts. Since the thermotropic model produces 1000- and 500-mb. level forecasts, the obvious choice for the 2-dimensional trajectory component was 750 mb., obtained by taking one-half of the sum of the two forecast levels. The 750-mb. charts were obtained by means of an electronic computer (IBM 701 EDPM).

Experimental forecasts were started on March 31, 1957 for Washington, D. C. Initially the trajectories were computed in 6-hr. steps as described in section 2, but starting on April 10 the trajectories were computed on the IBM 701 electronic computer from the thermotropic history tape. This was done in 1-hr. steps thereby increasing the accuracy of the trajectories. Also the trajectories were done for the intermediate times of 30 and 18 hours.

The forecast values of 700-mb. T_s (quasi 3-dimensional) for 12, 18, 24, 30, and 36 hours were plotted against time. The initial (observed) value of T_s at forecast point is also plotted and a smooth curve drawn. Initial and forecast w for 12, 24, and 36 hours is plotted against time and a smooth curve drawn. By means of the T_s–w–weather relationship, a forecast of clear, cloudy, partly cloudy, or precipitation is obtained for the entire 36-hr. period.

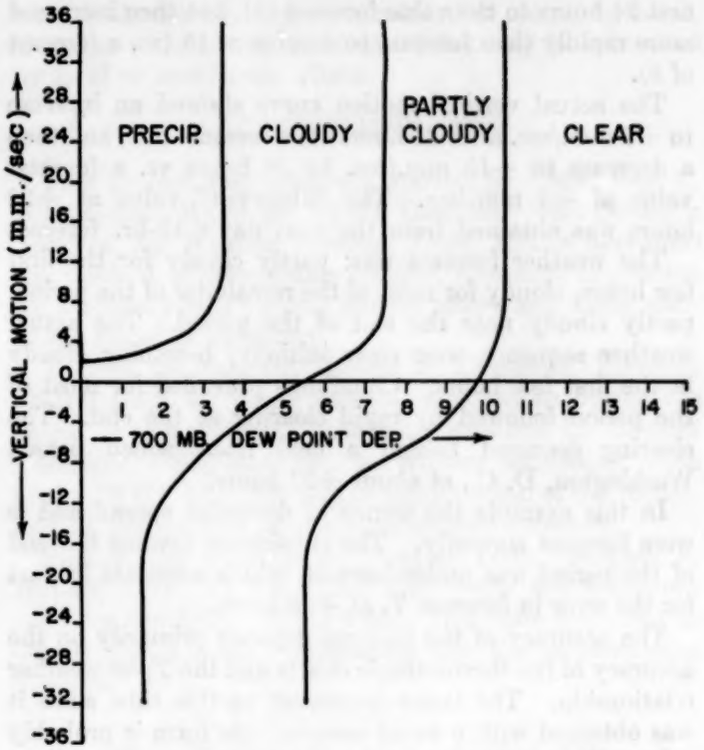

FIGURE 1.—Nomogram used for determination of weather categories, giving weather as a function of vertical motion in millimeters per second and the 700-mb. dewpoint depression in degrees Celsius. Enter nomogram with 700-mb. dewpoint depression and vertical motion and forecast weather indicated within envelopes.

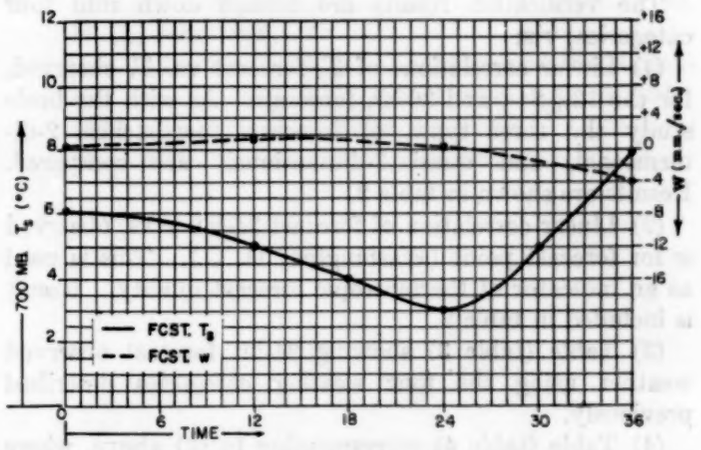

FIGURE 2.—Forecast example using machine-computed trajectories from 1-hour time steps. Forecast made from 1500 GMT, April 28, 1957. Weather forecast: Cloudy most of period, becoming partly cloudy evening of 29th.

Figure 2 is an example of a typical forecast. In this example the dewpoint depression is forecast to decrease gradually for the first 24 hours and then to increase gradually. The vertical motion is forecast to become slightly positive for the first 12 hours, to return to 0 at +24 hours, and to become negative by 36 hours.

The observed dewpoint depression decreased in the

first 24 hours to the value forecast (3), but then increased more rapidly than forecast to a value of 15 (vs. a forecast of 8).

The actual vertical motion curve showed an increase to +7 mm./sec. after 24 hours vs. a forecast of 0, and then a decrease to −13 mm./sec. by 36 hours vs. a forecast value of −4 mm./sec. The "observed" value at +36 hours was obtained from the next day's 12-hr. forecast

The weather forecast was: partly cloudy for the first few hours, cloudy for most of the remainder of the period, partly cloudy near the end of the period. The actual weather sequence was: clear initially, becoming cloudy in the first few hours. Cloudiness prevailed for most of the period followed by rapid clearing at the end. The clearing occurred behind a cold front which passed Washington, D. C., at about +22 hours.

In this example the trends of dewpoint spread and w were forecast correctly. The subsidence toward the end of the period was under-forecast, which accounts in part for the error in forecast T_s at +36 hours.

The accuracy of the forecast depends primarily on the accuracy of the thermotropic charts and the T_s–w–weather relationship. The latter is suspect at this time since it was obtained with a small sample. Its form is probably essentially correct but more data are necessary to put the relationship on a statistically reliable basis.

Some preliminary results of the forecasts have been computed. Thirty cases have been summarized, of which 22 had the advantage of machine-computed trajectories. The forecasts were obtained between March 31 and May 9, 1957.

The verification results are broken down into four categories; viz:

(1) Linear correlations of T_s forecast vs. T_s observed, for the 12-, 24-, and 36-hr. forecasts. As with the basic study the three types of forecasts (persistence, 2-dimensional, and quasi 3-dimensional) are compared. Results are shown in table 2.

(2) Linear correlation of forecast 24-hr. w vs. observed w for forecast point (Washington, D. C.). This is used as an indicator of thermotropic forecast quality. Result is included in table 2.

(3) Table (table 3) showing 24-hr. forecast observed weather using the four weather categories described previously.

(4) Table (table 4) corresponding to (3) above, where the weather forecasts were made using observed (verifying) T_s and w in place of the 24-hr. forecast values. This gives an indication of the accuracy of the weather indicator.

TABLE 2.—*Linear correlation between forecast and observed 700-mb. dewpoint depression. F_p=persistence, F_2=2-dimensional (no w), F_3=quasi 3-dimensional. Included is the linear correlation between 24. hr. forecast vs. observed w.*

	F_p	F_2	F_3
r (12 hr.)	0.50	0.69	0.80
r (24 hr.)	.35	.07	.63
r (36 hr.)	.08	.49	.47

r (w_f vs. w_o)=0.81

TABLE 3.—*24-hr. forecast vs. observed weather*

		Observed			
		Precipitation	Broken to overcast (middle and low clouds)	Partly cloudy (middle and low clouds)	Clear or high clouds
Forecast	Precipitation	1	2	0	1
	Broken to overcast (middle and low clouds)	1	4	2	1
	Partly cloudy (middle and low clouds)	0	4	0	1
	Clear or high clouds	0	1	3	9

TABLE 4.—*Forecast vs. observed weather using observed T_s and w as forecast values. (Same cases as table 3.)*

		Observed			
		Precipitation	Broken to overcast (middle and low clouds)	Partly cloudy (middle and low clouds)	Clear or high clouds
Forecast	Precipitation	3	4	0	0
	Broken to overcast (middle and low clouds)	0	5	1	0
	Partly cloudy (middle and low clouds)	0	1	4	1
	Clear or high clouds	0	1	1	9

The results in table 2 show that the 3-dimensional forecasts compare favorably with those obtained in the basic study (see table 1). The lower correlations for 24- and 36-hr. forecasts are to be expected using forecast charts. The results of the 2-dimensional forecasts are perplexing in that the 24-hr. result was very poor whereas the 36-hr. result was slightly better than the corresponding 3-dimensional forecast. This may be due to the smallness of the sample or perhaps the peculiarities of the weather regime during the period the forecasts were made. The persistence results seem more logical and compare favorably with those of the basic study.

The quality of the thermotropic forecasts is the major factor affecting the forecast results. By subjective criteria, the thermotropic forecasts for the 30 cases studied were, in general, good. The correlation between 24-hr. forecast and observed w of 0.81 confirms this. Note that this is only the w correlation for forecast point, and does not refer to the mean w used to alter the initial dewpoint spreads.

The verification of the weather forecasts is shown in table 3. The forecast weather was obtained from forecast T_s and w by means of the weather indicator (fig. 1). The exclusions to the categories are the same as explained previously. The results shown in the table are fairly good. In general, the forecast is only one category from the observed.

In order to test the accuracy of the weather indicator for these cases, the observed values of T_s and w were

used to obtain the forecasts. Results are shown in table 4. These are better than the corresponding results using forecast T_s and w, but still show discrepancies.

One thing indicated by the table is that the requirements for precipitation should be tightened. Three of the four cases of forecast precipitation which verified cloudy were just within the precipitation zone on the weather indicator (fig. 1).

5. CONCLUSIONS

The basic results show that the methods developed for forecasting middle atmosphere moisture are sound. The forecast moisture parameter (700-mb. T_s) along with the forecast vertical motion can then be used to obtain a forecast of large-scale cloudiness and precipitation. Preliminary results of experimental weather forecasts using the methods developed are favorable. It is of interest to note that in a recent vertical motion study at Pennsylvania State University [3], a primary conclusion was that an objective system of weather forecasting based on vertical motion should include moisture as an additional independent variable.

The forecast scheme can easily be adapted for machine computation of area weather forecasts. This is now in the planning stage.

The basic machine method under consideration is to compute the forecast dewpoint spread at each grid point by horizontal advection plus a vertical motion effect. This would be done hourly. By using the T_s–w– weather relationship, forecasts of large-scale cloudiness and precipitation could be printed out at desired times.

Results with machine-computed trajectories should be superior to those obtained by the manual technique, primarily because the vertical motion effect can be considered each hour, rather than as 6- or 12-hr. averages. Furthermore, area forecasts based on large-scale vertical motion should be more successful than point forecasts, since the weather at a particular point may be influenced by local or small-scale effects.

ACKNOWLEDGMENTS

This project was originally started by Capt. Earl C. Kindle, formerly of the JNWP Unit, now with Scientific Services, Air Weather Service. Capt. Kindle developed the method of forecasting 700-mb. dewpoint depression by trajectory plus vertical motion effect, and made some of the initial calculations.

Thanks are due Dr. George P. Cressman, Director, JNWP Unit, for many valuable suggestions during the course of this project. Thanks are also due Lt. Edward Carlstead, USN, and Mr. A. William McKnight, both of the JNWP Unit, for help in computation of the results, and in preparation of the experimental forecasts.

Finally, the writer is indebted to Lcdr. William E. Hubert, USN, JNWP Unit, who wrote the trajectory code for the IBM 701 EDPM. This code was used to obtain the 750-mb. trajectories for the experimental forecasts.

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WEATHER NOTES

THE UTAH STORM OF APRIL 22–23, 1957

INTRODUCTION

The upper air mean trough over the southern Plateau during April 1957 was favorable for intensification of low pressure systems moving into that area during the month. Several heavy storms swept through Utah with the unusual storm of April 22–23 bringing especially large amounts of precipitation to much of the State. Numerous precipitation records were broken and other interesting weather events occurred in this 2-day period.

The surface isobaric pattern preceding and during the heavy precipitation in Utah indicated no intense low pressure systems in the United States west of the Continental Divide. The upper air circulation was of prime importance during the storm so surface conditions will be mentioned only briefly.

DEVELOPMENT OF THE STORM

The 5-day period before the arrival of the storm in Utah was characterized by a trough at 500 mb. over western United States and a ridge in the Pacific at about 150° W. The 700-mb. mean chart for April 18–22 showed a closed Low over west-central Nevada.

The 500-mb. constant pressure chart for 1500 GMT, April 19 indicated a trough along the Pacific Coast of the United States, another over the eastern Rocky Mountain States, and a very weak ridge between the two troughs. During the next 24 hours the Pacific trough remained nearly stationary and deepened rapidly, forming a closed Low at 36° N., 124° W. which extended to the 200-mb. constant pressure level. The 500-mb. Low moved slowly southeastward and at 0300 GMT, April 22, it was centered on the California-Mexico border. Considerable moisture was being advected into Arizona and Utah at this time.

At 0030 GMT, April 22, a weak surface Low was present over southern Nevada. However, cyclogenesis was occurring over New Mexico and Colorado and by 0630 GMT, April 22 the Nevada Low had nearly disappeared. At this time the principal Low was over western Colorado. Intensification and slow north-northeastward movement of this system placed the center in southeastern Wyoming at 0630 GMT, April 23, with a central pressure of 996 mb., a deepening of about 7 mb. in the preceding 24 hours.

(Continued on p. 338)

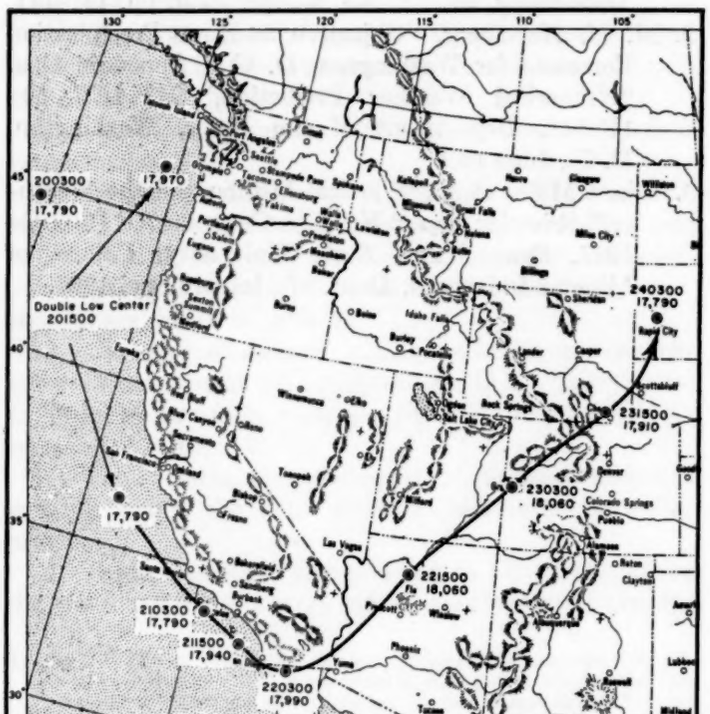

FIGURE 1.—Movement of the 500-mb. Low over western United States, 0300 GMT, April 20 to 0300 GMT, April 24, 1957. Plotted below each position circle is the approximate height, in feet, of the 500-mb. low center. Date and time (GMT) are plotted above.

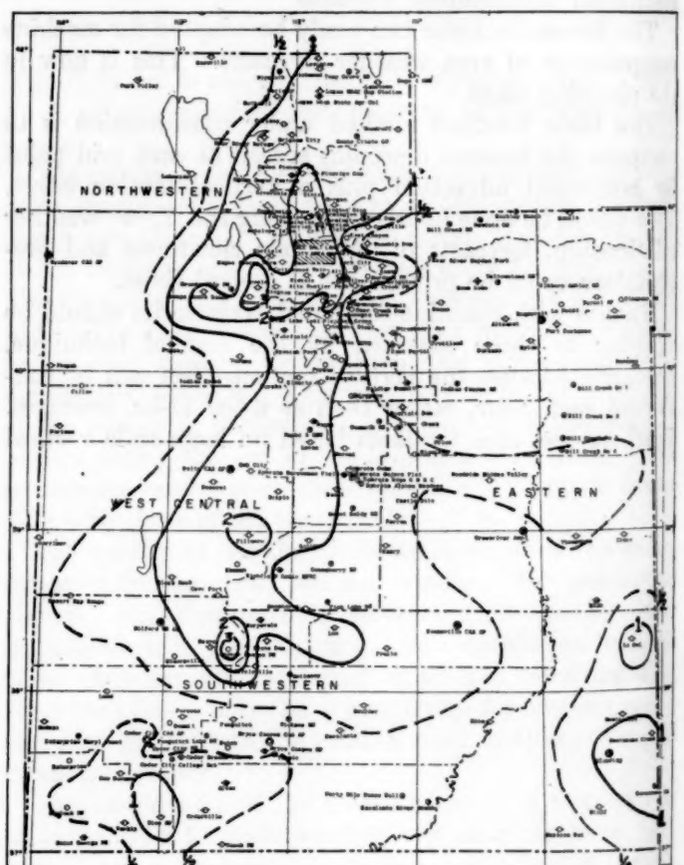

FIGURE 2.—Total precipitation (inches) in Utah, for April 22–23, 1957.

Correspondence

Comments on "A Possible Singularity in the January Minimum Temperature at Phoenix, Arizona"

ARNOLD COURT

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July 12, 1957

Mr. Kangieser uses the correct method of statistical analysis in his paper, "A Possible Singularity in the January Minimum Temperature at Phoenix, Arizona" (*Monthly Weather Review*, February 1957). But the manner in which his formulas are presented implies a different method, and hence may have confused some readers. After discussion at the Monterey meeting of the American Meteorological Society in June, where he presented his paper, and subsequent correspondence, Mr. Kangieser suggested that a clarification may be helpful.

The original article does not identify clearly the random variables under discussion, and the statistical hypotheses concerning them. The formulas imply a test of the difference between the means of the temperatures in the three periods studied, whereas actually Mr. Kangieser investigated the means of the temperature differences between periods. Since the distinction between these two approaches is not made clearly in many standard works on statistical methods, the following discussion is offered.

For notational simplicity, the mean minimum temperatures of the three successive 9-day periods in the ith year will be denoted as x_i, y_i, and z_i. (These correspond to Mr. Kangieser's T_{ai}, T_{bi}, and T_{ci}.) Since the differences between these variables are of primary interest, they are defined as

$$u_i=x_i-y_i; \qquad v_i=z_i-y_i$$

Minimum temperatures themselves are not exactly normal, but usually have some negative skewness, especially in winter. The mean of several minimum temperatures, however, should tend rather closely to a normal distribution. If observational conditions changed during the period under study, the variances of x, y, and z would be increased; in extreme cases, these variables might be bimodal or multimodal, and hence no longer normal. On the whole, however, the three random variables may be assumed to be each normally distributed with expected values (means) m_x, m_y, and m_z, and variances σ_x^2, σ_y^2, and σ_z^2.

These true but unknown population values are estimated from the sample means and variances, $\bar{x}$, $\bar{y}$, $\bar{z}$, and s_x^2, s_y^2, s_z^2. Throughout this discussion, s^2 is a sample variance; i. e., a mean square departure from the sample mean. It is not the same as the estimated population variance, which is $\hat{\sigma}^2=ns^2/(n-1)$.

The sum (or difference) of two normal random variables likewise has a normal distribution. Its mean is the sum (or difference) of the means of the two original variables, but its variance is the sum of the original variances plus (or minus) twice the covariance of these original variables. Specifically, for u

$$m_u=m_x-m_y;\ \sigma_u^2=\sigma_x^2+\sigma_y^2-2\sigma_x\sigma_y\rho_{xy},$$

where ρ_{xy} is the correlation coefficient of x and y. It measures the extent to which x and y tend to vary in the same way. Any extraneous factors that operate similarly throughout each set of three 9-day periods, such as changes in instrumental exposure, tend to make ρ_{xy} positive.

The formulas in Mr. Kangieser's paper imply that he tested the hypotheses

$$H_1:\ m_x=m_y+0.33;\ H_2:\ m_x=m_y+0.66$$

For such hypotheses, the usual test involves Student's t, but differs according to whether the two variances σ_x^2 and σ_y^2 are assumed to be equal or not. When they are considered equal, and with the same number, n, of observations on x and y,

$$(1) \qquad t=(\bar{x}-\bar{y}-0.33)\sqrt{(n-1)/(s_x^2+s_y^2)}$$

with $2(n-1)$ degrees of freedom.

This is the standard test for the significance of the difference between the means of two independent samples containing an equal number of observations from normally distributed populations with variances assumed to be equal. It is not proper, however, if the two samples are correlated, and hence not independent. When, as in the present case, the two samples are drawn in pairs, the pairwise differences, u and v, must be tested. This is what Mr. Kangieser actually did, as explained in the text of his paper. The actual hypotheses tested were

$$H_3:\ m_u=0.33;\ H_4:\ m_v=0.66$$

For these hypotheses, Student's t is also applicable, in the form

$$(2) \qquad t=(\bar{u}-0.33)\sqrt{(n-1)/s_u}$$

$$=(\bar{x}-\bar{y}-0.33)\sqrt{(n-1)/(s_x^2-2s_xs_yr_{xy}+s_y^2)},$$

with $n-1$ degrees of freedom.

[1] Maintained at Berkeley, Calif., in cooperation with the University of California.

Comparison of equations (1) and (2) indicates the extent of the difference between the two sets of hypotheses. In (2), the magnitude of t is increased because the denominator is reduced when the correlation r_{xy} is not zero. Although t in (2) has only half as many degrees of freedom as in (1), this is hardly important in the present case, where $n=62$. Significance at the 5 percent level is assumed when t exceeds 1.67 with 60 degrees of freedom, or 1.66 with 120 degrees of freedom. Even for much smaller samples the reduction in degrees of freedom usually is not as important as the effect of allowing for the possible correlation between the two sets of observations.

Another point that I raised at Monterey after hearing Mr. Kangieser's paper concerns the hypotheses themselves. Although he tested H_3 and H_4, his question involved rather

$$H_5: m_u \leq 0.33; \qquad H_6: m_v \leq 0.66$$

The difference is that H_3 and H_4 require two-tailed tests, rejecting the hypotheses if the absolute value of t exceeds the critical value, while H_5 and H_6 require one-tailed tests, rejecting only if the numerical value of t exceeds the critical amount. Hence these tests are more appropriate.

Mr. Kangieser indicated orally that a one-tailed test would be too great a refinement, because of the possible bias in that the 9-day periods were selected for test after inspection of the data. Such a possible bias can be countered more realistically in the level of significance chosen than in the use of a less appropriate test.

Reply

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I would like to thank Dr. Court for raising these points and appreciate very much his rigorous mathematical demonstration of them in original correspondence that is somewhat more lengthy than that published here.

I would like to comment further on only the last two paragraphs of Dr. Court's note.

I believe that the question of whether or not to use a one-sided test here is an open one. If there had been an a priori reason for thinking that the temperatures in period B were higher than those in either periods A or C, I would have used a one-sided test. This might be the case in testing a physical hypothesis, conceived a priori and independently of the temperature data. For example, if a dynamic meteorologist showed me a series of calculations, based on physical reasoning, which developed a hypothesis that could be checked by showing that the mean minimum temperatures in period B are significantly higher than those in periods A or C, then I would follow the procedure outlined in my paper, but test the hypotheses (following Dr. Court's notation):

$$H_5: m_u \leq 0.33 \qquad H_6: m_v \leq 0.66$$

If H_5 and H_6 were true, then there would be strong evidence for believing the dynamic meteorologist's physical hypothesis.

In my problem, however, I have no reason to believe (except by subjective inspection of the data) that temperatures in period B are either higher or lower than those in A and C. My best estimate of the situation is expressed by

$$H_3: m_u = 0.33 \qquad H_4: m_v = 0.66$$

As mentioned by Dr. Court, these are the hypotheses actually tested in my study, contrary to the impression left by my paper. If a test of these shows that t lies above or below the critical region, then I can say, subject to the important reservations discussed in points (1), (2), and (3) on p. 44 of my original paper, that there is evidence that the temperatures in period B are either higher or lower than those in A and C, depending on whether t is above or below the critical region, respectively. In other words, I feel it should be a question here of being "innocent until proved guilty" and that the data themselves should be given as much room as possible to do the judging.

THE 1957 DROUGHT IN THE EASTERN UNITED STATES

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ABSTRACT

Various aspects of the Eastern United States drought of 1957 are discussed and some of the pertinent data are tabulated and summarized. These include amount of the summer rainfall, a derived and experimental measure of "moisture adequacy," and the 5-month percentage of long-term mean precipitation—by climatological divisions insofar as possible.

Some of the unusual and record-breaking aspects of the weather during the spring and summer are listed and monthly precipitation reports from 113 selected points from Virginia to Maine are tabulated. In addition actual measurements of soil moisture are tabulated for a number of locations.

The worst of the moisture deficiency occurred in the coastal strip from inner Cape Cod to the Virginia Capes, a conclusion borne out by summaries of the streamflow and ground-water measurements of the Geological Survey as well as by the crop condition reports of the Agricultural Marketing Service.

1. INTRODUCTION

After Samuel Johnson issued (in 1755) his pioneer English dictionary a lady asked him why he had incorrectly defined "pastern" as "the knee of a horse." Dr. Johnson replied, "Ignorance, Madam, pure ignorance."

This story is an appropriate preface to an article on drought, because ignorance on this subject is not only pure but widespread. Of course, a farmer surveying his parched crops and withered pastures does not need a dictionary or scientific treatise to know that a water shortage exists. The trouble with defining and describing this shortage is the fact that drought involves many factors, which are inadequately measured, incompletely understood, and highly variable as regards location, kind of crop, type of soil, time of year, etc.

In general, there are two climatological approaches to a discussion of drought. It is easier to take the "high road" and treat the subject in terms of rainfall deficiencies. This approach is justified insofar as there exists a useful relationship between rainfall and crop response; but simply defining drought as a lack of precipitation does not even begin to tell the whole story. For example, a month with frequent light rains resulting in low total rainfall may look like a dry month, but actually may be more favorable to plant growth than a month with a high total, the result of a heavy downpour or two.

As a gross measure of drought, however, deficient rainfall is usable; crop damage in the Northeast is certainly indicated by the map of total precipitation for the summer (June-August) 1957 (fig. 1). This map shows in general, that only about 4 to 8 inches of rainfall occurred during the summer over southern New England, southern New York, New Jersey, most of Pennsylvania, Delaware, Maryland, and West Virginia. Since the normal June-August rainfall for these areas ranges between approximately 10 inches along the Massachusetts coast and 14 inches in the West Virginia mountains, it is apparent that the something known as drought must have affected certain areas and certain crops for certain periods during the summer. The moral is that the "high road" to drought, though broad and easy to follow, does not lead very far by itself.

2. MOISTURE ADEQUACY

To take the "low road" is to follow the rainfall into the ground and try to arrive at an evaluation of drought through the complex interrelationships that were mentioned above. Several methods have been devised for

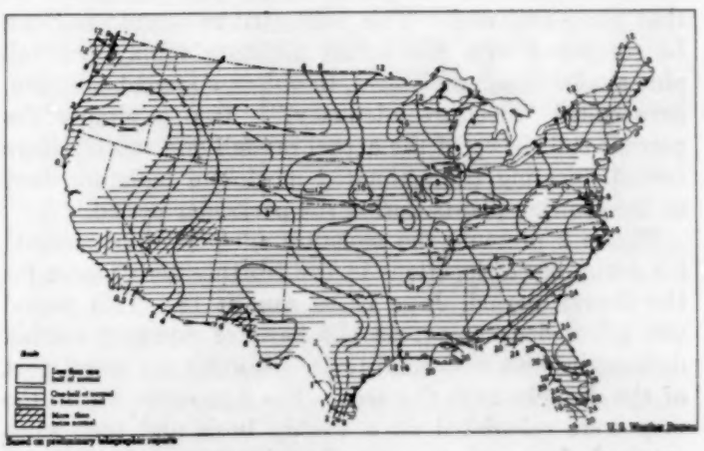

FIGURE 1.—Total precipitation, inches, summer (June–August) 1957. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLIV, No. 36, Sept. 9, 1957.)

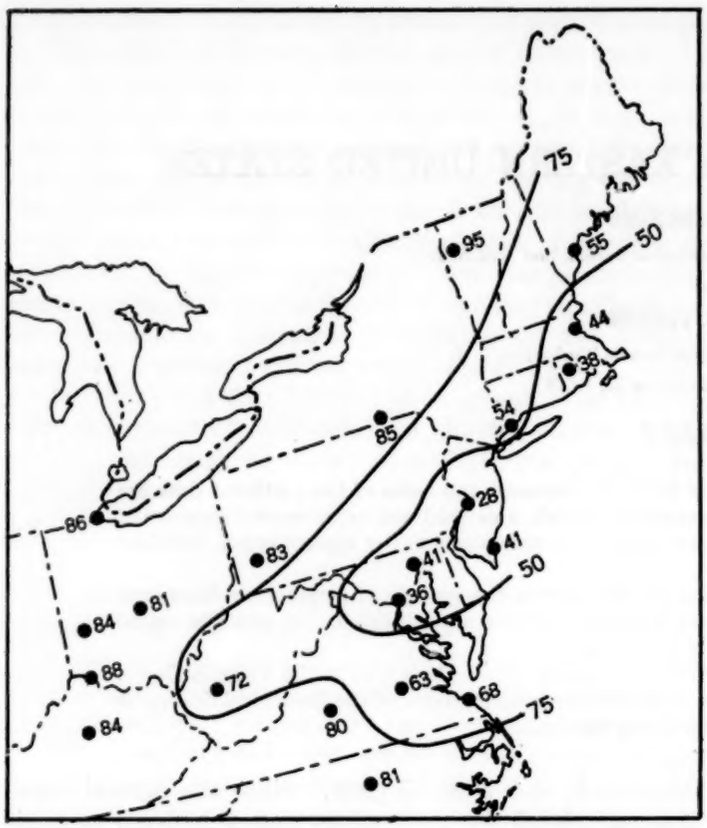

FIGURE 2.—Percentage of moisture adequacy, June 17–August 18, 1957.

accomplishing this objective, all involving assumptions and simplifications. One of these methods makes use of the idea of "moisture adequacy."

This idea was developed from the concept of potential evapotranspiration [1], which is defined as the amount of water given up to the atmosphere from a surface completely covered with vegetation that at no time is limited by soil moisture. Potential evapotranspiration can be approximated for any place for any given period of time from climatological data. It represents the estimated maximum moisture requirement of the vegetation at that place and time. This estimated moisture need can be compared with the actual moisture supply (rainfall plus available soil moisture), to obtain a second estimate, here called "moisture adequacy." This is simply the percent sufficiency of the actual rainfall and soil moisture toward meeting the estimated maximum moisture need of the growing plants during the particular period.

Figure 2 presents the moisture adequacy (in percent) for a number of locations in the Northeastern States for the 9-week period, June 17 to August 18. This period was selected as being, on the basis of reported rainfall deficiencies and crop conditions, generally the worst part of the drought over the area. The figures shown on the map were calculated on a weekly basis and then summarized, from (a) the actual moisture supply (rainfall plus available soil moisture used during the period), which is the estimated actual use, divided by (b) the potential evapotranspiration, or the estimated maximum requirement. For example, at Washington, D. C., quantity (b) during the June 17–August 18 period was 13.10 inches; but rainfall of only 2.60 inches, and soil moisture withdrawal of 2.08 inches, gave quantity (a) the value of 4.68 inches. In other words, the moisture adequacy of this supply of 4.68 inches was rated as only 36 percent of the 13.10 inches that would give lush vegetative growth.

The above explanation, if not unduly confusing, should make two things clear. First, this notion of moisture adequacy is proposed experimentally, in an attempt to relate the weather factors usually but imprecisely associated with drought more closely to the actual moisture conditions experienced by the growing vegetation. Because of the assumptions underlying the idea, figure 2 is presented tentatively and should not be taken literally. It seems reasonable, however, to suspect that crop production may be linked with moisture adequacy, when the latter is computed for critical phenological periods, though there has not yet been enough experience with this type of derived climatological information to permit the determination of "critical values" or relationships with other pertinent factors.

The second point is the impossibility of using moisture adequacy values, when plotted and analyzed as in figure 2, to show anything but the general drought pattern. One basic reason for this limitation is the great areal variability of rainfall, especially in the case of small-scale showers and local thunderstorms. Even over so small an area as the District of Columbia and environs, for instance, amounts varied considerably during the 4-month period, April through July 1957. Twenty stations in an area about 20 miles square indicated a mean rainfall of 10.26 inches for the area during the 4 months. (The normal for this period is 14.64 inches at the Washington, D. C. Weather Bureau Office.) Falls Church, Va., located about 7 miles west of the Weather Bureau Office, received only 7.93 inches during the 4 months, whereas Beltsville, Md., about 14 miles northeast of the Weather Bureau Office, received 12.78 inches. Undoubtedly a more dense network of reports would have shown still greater variation. Thus, one of two nearby places may suffer from deficient moisture while the other may enjoy average rainfall. This circumstance, to say nothing of the different water-holding capacities of different soils and the varying water needs of various drops, inevitably makes the approach to the drought problem illustrated by figure 2 very generalized.

3. RAINFALL DEFICIENCIES

Nevertheless, there is reasonably good agreement between the picture presented in figure 2 and the drought situation as described by other indicators. To go into the rainfall distribution in some detail, the Weather Bureau's regular and cooperative observing network provides a fairly dense coverage over the East, except in the mountainous districts. For the mid-June to mid-August period, rainfall measurements from these sources

gave the following general picture. (1) Rainfall was 75 percent of normal or above only in northern New York, extreme northern Vermont and New Hampshire, and the northern half of Maine. (2) The 9-week totals were 50 to 75 percent of normal in the remainder of the above-mentioned States (except southeastern New York), and over the western halves of Pennsylvania, Maryland, and Virginia and all of West Virginia. (3) Less than 50 percent of normal rainfall was received in the coastal belt: southern New England, southeastern New York, New Jersey, Delaware, and the eastern portions of Pennsylvania, Maryland, and Virginia.

This pattern conforms to that of figure 2. In addition, the temperature pattern during the same period was roughly the opposite; that is, above normal temperatures in the interior of the Northeast. It is well known that, other things being equal, growing plants yield to the atmosphere more moisture with increasing temperatures; thus, a given rainfall deficiency may result in drought if accompanied by relatively high temperatures, but not if the temperatures are comparatively low. In sum, the combined temperature-rainfall distribution over the Northeast this past summer was such that the maximum need for moisture was created where deficiencies and losses were the greatest.

Table 1 presents some of the more interesting and unusual aspects of the rainfall deficiencies and other anomalies. From the data and remarks in the table it is apparent that record dryness occurred at many places and times during the spring and summer of 1957. In a number of instances, such as at New York in August, a large portion of the month's rainfall occurred in a single storm. Such heavy downpours are not mentioned solely as oddities. They are rather characteristic of summer dry spells, and tend to "falsify" the comparative statistics, for they usually occur in a matter of hours and the rain runs off so rapidly that vegetation receives comparatively little benefit. If table 1 is considered in the light of figure 2, it is apparent that the Weather Bureau data confirm the moisture adequacy values in their most important respects.

Records of the cooperative observers provide additional details concerning the spring and summer of 1957. A selected sample of the reports of regular Weather Bureau

TABLE 1.—*Some unusual aspects of the spring and summer of 1957*

Place	Time	Precipitation (in.)	Percent of normal	Remarks
Portland, Maine	April	1.91	51	Many forest fires.
	May	2.28	68	5th consecutive month below normal.
	June	2.38	72	1.14 in. of rain on 25th.
	July	1.34	47	No rain greater than 0.31 in. after 5th.
	August	.80	31	Driest August since 1947 and coldest August since 1927.
Boston, Mass.	April	4.46		1.09 in. above normal; 0.35 in., April 10 to May 9.
	May	3.63		0.72 in. above normal; mean temperature 2.1° F. above normal.
	June	1.62	46	Warmest June since 1949.
	July	.64	20	2d driest since 1818; 1952—0.52 in.
	August	1.71	53	Driest June-August on record.
Providence, R. I.	April	4.46		1.09 in. above normal; 4.20 in. in 1st 9 days.
	May	.93	31	3d driest May on record.
	June	.39	12	2d driest June on record.
	July	1.41	46	All ineffective showers of less than 0.50 in.
	August	2.51	69	40% of total fell in 2 hours on 10th.
	May–July		30	4th lowest % of May-July normal on record among 19 Eastern cities investigated. May-July total was 29% of normal at Baltimore, Md., in 1869, at Salisbury, Md., in 1911 and at Columbus, Ohio, in 1930. In 1934 Ft. Worth, Tex., had only 9% of normal during these 3 months and Waco, Tex., only 18% of normal [2].
Bridgeport, Conn.	April	4.06	116	Temperature 3.7° above normal.
	May	2.14	60	Temperature 4.5° above normal; 1.15 in. on 14th.
	June	.40	12	Temperature 4.7° above normal; 2d driest June in 52 yrs.; 0.07 in. in 1949.
	July	2.84	71	Ineffective showers except 0.68 on 13th and 1.41 in. on 29th.
	August	2.92	66	Temperature 1.7° F. below normal; good showers on 4th, 15th, 25th.
New York, N. Y.	April	5.46	170	Temperature 3.0° F. above normal.
	May	1.51	43	4th driest May since 1900.
	June	1.29	35	Temperature 3.4° F. above normal; warmest June since 1943; 2d driest June since 1912, 0.16 in. in 1949.
	July	1.73	41	Only one good rain, 1.12 in. on 13th; 87% of maximum possible sunshine; temperature 1.4° F. above normal.
	August	2.91	67	Only one rain of consequence, 1.99 in. in 24 hrs. on 25–26th. The driest May-August in 120 yrs. of record.
Trenton, N. J.	April	4.93	164	Last 14 days of month averaged 9.6° F. above normal.
	May	1.40	40	Driest May since 1944; 0.71 in. of rain fell in 1 hr. on 20th.
	June	1.47	38	Warmest June (+3.7° F.) since 1943; all rains were ineffective light showers of less than 0.30 in.
	July	1.23	30	6th driest July since 1911; each rain was less than 0.50 in.
	August	1.10	24	2d driest August of record, 0.92 in. in 1869; driest May-August on record.
Atlantic City, N. J.	April	2.28	67	Temperature last 10 days of month averaged 8.6° F. above normal; rain fell on 20 of the 30 days.
	May	.54	18	Driest May since 1911.
	June	2.76	92	No rain of consequence after the 8th.
	July	.31	8	2d driest July since 1874, 0.15 in. in 1894.
	August	3.38	72	Temperature 2.5° F. below normal; good showers on 4th, 15th, 19th, 25–26th; some recovery from drought conditions.
Baltimore, Md.	April	2.46	66	No rain of consequence after the 8th; last 10 days averaged 13.4° F. above normal.
	May	.55	14	Driest May on record.
	June	4.18	119	Temperature 3.7° F. above normal; maximum temperature 90° F. or above 12–19th; no rain of consequence 8–24th.
	July	1.82	46	Only 4 days with rain, 2d lowest number since 1871, 2 days in 1955.
	August	1.09	25	6th driest August since 1871; no rain of consequence until August 25 when 0.80 in. fell.
Washington, D. C.	April	3.24	101	No rain of consequence after 8th; last 13 days averaged 13.2° F. above normal.
	May	3.16	81	2.79 in. on 13–14th; monthly total at Airport—1.40 in.
	June	3.01	88	The only rain of consequence after the 5th was 0.67 in. on 23d.
	July	1.00	24	2d driest July on record, 0.82 in. in 1872.
	August	2.09	47	Only rain of consequence was 1.64 in. on 25th.

TABLE 2.—*Precipitation and its departure from normal*

	April 1957		May 1957		June 1957		July 1957		August 1957		5-month total		
	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Percent
VIRGINIA													
Tidewater	2.36	−0.82	2.23	−1.35	3.73	0.14	2.07	−3.24	6.13	0.82	16.52	−4.45	79
Diamond Springs	2.40	−.96	2.02	−1.58	3.73	−.09	1.99	−4.26	6.29	−.29			
Fredericksburg	1.69	−1.46	1.29	−2.31	4.29	1.09	.74	−4.30	6.55	1.70			
East Piedmont	3.29	−.19	2.47	−1.28	3.59	−.10	1.81	−3.23	4.88	.11	16.04	−4.69	77
Farmville	2.68	−.89	2.64	−1.36	4.72	.25	2.16	−2.93	5.33	.61			
Richmond	2.25	−.98	2.75	−.89	3.92	.05	1.80	−3.84	7.46	2.41			
West Piedmont	5.03	1.49	2.61	−1.44	5.06	.79	2.35	−2.64	3.24	−1.52	18.29	−3.32	85
Bedford	4.79	1.36	3.62	−.63	3.78	−.81	1.74	−2.81	2.34	−3.17			
Charlottesville	4.63	.92	3.33	−.70	3.45	−.68	2.32	−3.23	1.35	−3.50			
Danville	4.96	1.56	2.47	−1.88	4.14	.30	.70	−3.90	4.69	.52			
Northern	3.43	.13	2.29	−1.97	3.53	−.16	1.46	−2.73	1.57	−3.33	12.28	−8.06	60
Culpepper	3.40	−.28	3.19	−1.08	2.68	−1.01	.82	−3.95	1.86	−2.62			
Mount Weather	3.10	−.22	3.86	−.40	4.69	1.09	2.58	−.93	1.90	−2.77			
Central Mountain	5.05	2.05	3.02	−.85	5.36	1.38	1.82	−2.53	1.28	−3.33	16.53	−3.28	83
Dale Enterprise	4.88	2.44	3.32	−.67	4.54	.61	1.71	−2.88	.23	−4.16			
Hot Springs	5.13	2.14	2.73	−.92	6.51	2.26	3.05	−1.16	2.11	−2.66			
Southwestern Mountain	5.06	1.84	2.70	−1.24	5.38	1.32	2.99	−2.09	2.12	−2.28	18.25	−2.45	88
Dante	4.31	1.06			5.39	.67	.93	−5.15	2.11	−2.56			
Wytheville	4.31	1.60	2.96	−.66	4.31	1.11	4.82	.57	1.93	−2.19			
MARYLAND													
Southern Eastern Shore	2.52	−.91	1.30	−2.25	3.60	.10	1.65	−2.94	4.58	−.97	13.65	−6.97	66
Crisfield	2.72	−.92	1.47	−2.23	2.29	−1.18	1.57	−3.42	5.97	.90			
Salisbury	3.17	−.16	.69	−3.04	3.34	−.29	1.38	−2.84	2.97	−3.32			
Central Eastern Shore	1.79	−1.65	1.23	−2.86	3.43	−.19	1.14	−3.43	3.17	−2.02	10.76	−10.15	51
Easton, Police Barracks	2.00	−1.59	1.99	−2.04	3.02	−.46	.91	−3.42	3.28	−1.69			
Lower Southern	2.19	−1.36	.78	−3.29	3.78	.26	2.01	−2.86	5.64	.28	14.40	−6.97	67
Owings Ferry Landing	1.85	−1.72	.31	−6.98	2.53	−.82	1.01	−3.01	7.02	1.57			
Solomons	2.87	−.62	1.48	−2.41	4.02	.52	2.09	−3.14	5.63	.52			
Upper Southern	2.72	−.70	1.75	−2.47	3.89	.06	1.85	−2.13	2.66	−2.35	12.87	−7.59	63
Annapolis, USN Academy	1.64	−1.77	.73	−3.26	3.33	−.25	2.01	−1.89	2.05	−2.54			
Washington, D. C., WBO	3.24	.04	3.16	−.75	3.01	−.41	1.00	−3.11	2.09	−2.40			
Northern Eastern Shore	1.99	−1.47	1.68	−2.30	2.87	−.64	1.05	−3.20	2.99	−1.93	10.58	−9.63	52
Millington	1.95	−1.41	2.86	−1.17	2.55	−.81	1.22	−2.70	3.01	−1.93			
Northern Central	3.66	.09	2.61	−1.70	3.64	−.22	1.70	−2.31	1.87	−2.88	13.48	−7.02	66
Aberdeen, Phillips Field	3.75	.55	2.70	−1.31	4.66	1.33	1.18	−2.49	2.86	−.81			
Frederick, WBAS	4.31	.81	2.45	−1.15	2.61	−1.35	1.26	−2.39	1.99	−2.04			
Westminster	4.58	.87	2.38	−1.59	2.54	−1.70	2.21	−1.84	1.72	−3.36			
Appalachian Mountains	4.13	.90	2.04	−1.91	4.15	.27	2.22	−1.35	1.04	−2.89	13.58	−4.98	73
Chewsville, Bridgeport	3.34	.30	1.44	−2.61	4.07	.46	1.41	−2.01	1.30	−2.91			
Picardy	3.75	.80	2.71	−.86	4.86	1.15	3.19	−.27	.93	−3.10			
Allegheny Plateau	4.17	.23	2.56	−1.92	4.00	−.71	3.17	−1.15	1.55	−2.90	15.45	−6.45	71
Sines Deep Creek	4.39	.19	2.37	−2.27	4.30	−.78	3.04	−1.70	1.53	−2.94			
DELAWARE													
Northern	3.84	.27	1.66	−2.56	3.34	−.56	1.58	−2.59	3.14	−2.20	13.56	−7.64	64
Wilmington, WBAS	3.73	.09	2.36	−1.45	3.45	−.57	1.33	−3.16	2.61	−2.67			
Southern	1.78	−1.83	1.60	−2.50	5.03	1.44	1.09	−3.40	2.50	−3.24	12.00	−9.53	56
Bridgeville	1.52	−2.02	1.49	−2.51	8.47	5.05	.71	−3.98	1.67	−3.98			
WEST VIRGINIA													
Northwestern	4.29		3.04		1.13		2.17		.90		14.53		
New Martinsville	4.44	.94	2.78	−.89	3.19	−.92	2.12	−2.37	.98	−2.91	13.51	−6.15	69
Parkersburg, WBO	3.26	.18	4.10	.60	4.42	.24	2.75	−1.41	.73	−3.42	15.26	−3.81	80
North Central	3.99		3.07		3.47		2.44		1.34		14.31		
Clarksburg	3.34	−.03	1.96	−1.72	2.73	−1.54	1.82	−2.26	1.57	−2.01	11.42	−8.46	57
Glenville	3.36	−.40	2.96	−1.16	3.66	−.73	4.85	−.02	.31	−3.92	15.14	−6.23	71
Southwestern	3.06		2.72		3.18		3.11		1.25		13.32		
Charleston, WBAS	2.60	−1.14	2.83	−.95	1.69	−2.24	4.27	−1.18	.66	−3.89	12.05	−9.40	56
Logan	2.54	−1.61	1.56	−2.55	2.17	−2.72	4.59	−.34	2.42	−2.07	13.28	−9.29	59
Central	4.77		2.92		6.08		3.51		2.19		19.47		
Beckley, VA Hospital	2.68	−.80	2.58	−1.05	2.79	−1.62	2.95	−1.43	3.00	−.84	14.00	−5.74	71
Kumbrabow State Forest	7.37	2.21	3.53	−2.59	8.51	2.14	3.95	−3.00	1.96	−3.24	25.32	−4.48	85
Rowlesburg	4.39	.20	2.93	−1.79	5.02	−.35	4.31	−.89	1.13	−3.40	17.78	−6.23	74
Southern	3.08		2.01		4.50		2.30		2.00		13.89		
Gary	4.38	.89	1.77	−2.20	5.07		3.86	−1.07	1.85	−2.26	16.93	−4.64	78
Union	3.47	.58	1.72	−1.48	3.97	−.02	2.00	−1.79	1.74	−2.19	12.90	−4.90	72
Northeastern	3.58		2.02		4.20		2.31		.72		12.83		
Martinsburg	3.81	.70	1.76	−1.63	3.34	−.80	2.17	−1.45	.84	−3.22	11.92	−6.40	65
Petersburg	3.37	.54	2.44	−.85	3.70	.22	1.40	−1.93	.49	−2.74	11.40	−4.76	71
PENNSYLVANIA													
Pocono Mountains	6.54		2.47		4.05		2.58		1.52		17.16		
Pleasant Mount	5.82	1.97	2.93	−1.70			6.27	1.20	2.16	−1.95	17.18	−.48	97
Scranton, WBAS	5.81	2.56	1.44	−2.67	4.01	−.42	2.05	−3.28	1.38	−2.70	14.69	−6.51	69
East Central Mountains	6.59		2.18		4.01		1.34		1.17		15.29		
Allentown, WBAS	6.49	3.10	2.35	−1.62	3.88	−.17	1.05	−3.73	1.39	−3.10	15.16	−5.52	73
Southeastern Piedmont	4.89		1.40		2.85		1.36		1.46		11.96		
Lebanon	5.47	2.01	2.10	−1.91	4.97	.84	1.30	−3.25	.55	−3.71	14.39	−6.02	70
Phoenixville	5.17	1.79	1.13	−3.10	1.85	−2.02	1.26	−3.56	1.67	−3.05	11.08	−9.94	53

See footnote at end of table

TABLE 2.—*Precipitation and its departure from normal*—Continued

	April 1957		May 1957		June 1957		July 1957		August 1957		5-month total		
	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Percent[1]
Lower Susquehanna	4.19		1.65		4.20		2.05		1.70		13.79		
Chambersburg	4.08	.91	1.34	−2.46	7.03	3.06	2.24	−1.52	1.33	−2.60	16.02	−2.61	
York	4.55	1.32	1.02	−2.70	2.42	−1.34	1.59	−2.66	2.32	−1.92	11.90	−7.30	
Middle Susquehanna	5.41		1.79		4.71		1.29		1.14		14.34		
Newport	5.15	1.65	1.21	−3.10	5.81	2.20	1.09	−3.42	1.51	−2.72	14.77	−5.39	
Williamsport, WBAS	6.30	2.76	1.93	−2.38	5.74	2.32	1.65	−2.06	1.25	−2.36	16.87	−1.72	
Upper Susquehanna	5.71		2.74		3.85		3.17		2.24		17.71		
Towanda	5.44	2.46	3.39	−.21	2.90	−.76	3.19	−.69	3.17	−.15	18.09	.65	104
Wellsboro	5.47	2.19	2.89	−.98	2.91	−.83	3.06	−.62	2.55	−1.08	16.88	−1.32	93
Central Mountains	5.61		2.07		5.12		2.50		1.89		17.19		
Du Bois	5.20	1.62	2.04	−2.52	4.75	.39	1.54	−3.00	2.91	−.37	16.44	−3.88	81
State College	5.31	1.90	1.64	−2.47	6.94	2.90	2.79	−1.43	2.76	−.49	19.44	.41	102
South Central Mountains	5.20		2.16		5.41		1.98		1.13		15.98		
Altoona, Horseshoe Curve	5.07	1.41	4.04	−.09	7.21	3.03	1.80	−2.20	1.47	−2.04	19.59	.11	101
Everett	4.88	1.79	1.68	−2.02	4.62	−.01	2.02	−1.84	.48	−3.35	13.68	−5.43	72
Southwest Plateau	5.22		2.74		4.14		2.62		1.15		15.87		
Newcastle	5.53	2.44	3.97	.42	4.49	.34	2.93	−1.23	2.35	−.96	19.27	1.01	106
Pittsburgh, WBO	4.94	1.86	2.72	−.77	4.75	.92	2.83	−.89	.29	−2.79	15.53	−1.67	90
Uniontown	3.31	−.42	2.45	−1.69	2.60	−2.25	3.17	−1.58	.80	−3.67	12.33	−9.61	56
Northwest Plateau	3.73		2.91		6.18		2.17		1.78		16.77		
Clarion	6.64	2.89	2.96	−1.25	4.79	.09	2.84	−1.73	2.70	−1.19	19.93	−1.19	94
Corry	5.89	2.10	2.11	−1.85	7.11	2.30	2.99	−.60	2.56	−.84	20.66	1.11	106
Kane	6.38	2.43	3.31	−1.41	4.98	.33	1.46	−2.95	1.75	−1.88	17.88	−3.48	84
NEW JERSEY													
Northern	5.81	2.03	2.71	−1.58	2.23	−1.93	1.80	−2.82	2.08	−2.99	14.63	−7.29	67
Flemington	5.55	1.90	1.00	−3.34	3.30	−.62	.97	−3.41	1.28	−4.05			
Newton	5.56	1.96	1.82	−2.42	1.96	−2.51	2.11	−2.57	1.30	−3.36			
Southern	4.01	.57	1.03	−2.96	2.14	−1.57	.97	−3.08	2.08	−3.12	10.23	−10.16	50
Hammonton	2.45	−1.22	.55	−3.60	4.39	.35	.71	−3.48	1.82	−4.13			
New Brunswick, Experiment Station	5.66	2.32	.96	−3.03	2.19	−1.64	1.31	−2.94	3.66	−1.12			
Coastal	3.78	.53	.78	−2.59	2.11	−1.06	1.03	−2.38	2.49	−2.42	10.19	−7.92	56
Atlantic City, WBO	2.28	−1.12	1.54	−2.44	2.76	−.23	.31	−3.47	3.38	−1.34			
Long Branch	5.64	2.10	1.00	−2.64	1.43	−2.16	.84	−3.25	2.82	−2.55			
NEW YORK													
Western Plateau	5.32	2.22	3.83	−.08	4.03	.37	3.15	−.60	1.32	−2.14	17.65	−.23	99
Angelica	4.65	2.05	3.74	.32			2.76	−.77	.83	−2.04			
Elmira	5.02	2.17	3.84	−.22	3.69	.26	3.16	−.34	1.22	−2.90			
Eastern Plateau	3.95	.69	3.81	−.07	3.12	−.56	3.81	−.39	2.18	−1.83	16.87	−2.16	89
Norwich	4.33	1.11	3.73	.03	4.97	1.23	4.30	.01	2.82	−.88			
Roxbury	3.12	−.48	5.21	1.12	2.83	−1.04	3.25	−.84	1.42	−2.73			
Northern Plateau	2.70	−.56	3.99	.43	5.16	1.66	4.19	−.02	1.02	−2.63	17.06	−1.12	94
Lowville	2.47	−.64	3.67	.55	4.46	1.78	3.88	.61	.80	−2.36			
Tupper Lake, Sunmount	2.11	−.55	3.42	.12	4.26	.96	3.36	−.68	2.04	−1.83			
Atlantic Coast	5.26	1.60	2.56	−1.23	1.53	−2.01	2.27	−1.28	3.53	−1.32	15.15	−4.24	78
Bridgehampton	3.93	.33	1.98	−1.55	.22	−2.74	1.57	−1.02	3.27	−1.38			
Scarsdale	5.03	1.01	2.55	−1.93	2.22	−1.74	3.90	−.58	3.15	−1.87			
Hudson Valley	3.47	−.08	3.28	−.73	2.55	−1.41	3.42	−.86	1.77	−2.28	14.49	−5.36	73
Albany WBAS	2.25	−.36	4.94	2.14	2.36	−1.01	2.17	−1.13	1.66	−1.23			
Poughkeepsie	4.99	1.42	2.15	−1.64	1.69	−2.00	2.02	−2.11	1.49	−2.52			
Mohawk Valley	3.06	−.53	3.64	−.08	3.86	−.12	5.31	.79	2.29	−1.62	18.16	−1.56	92
Gloversville	2.58	−1.07	3.57	−.25	2.90	−1.12	6.00	1.73	2.50	−1.34			
Little Falls, City Reservoir	2.41	−.97	3.97	.36	3.44	−.56	5.64	1.08	2.59				
Champlain Valley	1.48	−1.47	3.47	.34	4.03	.64	3.56	−.12	.95	−2.38	13.49	−2.99	82
Dannemora	1.44	−1.50	4.45	1.17	3.69	.17	4.22	.67	.39	−2.86			
Whitehall	1.65	−1.49	3.41	.16	2.92	−.63	2.19	−1.90	2.42	−1.00			
St. Lawrence Valley	2.32	−.65	3.86	.58	4.15	1.29	3.25	−.35	.29	−2.77	13.87	−1.90	88
Canton	2.26	−.74	3.79	1.57	3.27	.11	3.18	−.55	.23	−2.89			
Lawrenceville	2.25	−.53	4.43	1.07	3.23	.12	3.94	.34	.09	−3.26			
Great Lakes	3.67	.73	3.52	.41	4.10	1.36	2.86	−.05	1.10	−1.72	15.25	.73	105
Buffalo, WBAS	4.86	2.31	4.03	1.56	2.92	.22	2.97	.54	1.11	−1.43			
Oswego, Teachers College	2.06	−.68	3.45	.52	4.00	1.85	2.89	.22	1.42	−1.11			
Rochester WBAS	2.77	.13	2.98	.34	3.63	.78	2.24	−.85	.96	−1.52			
Central Lakes	3.56	.78	3.95	.81	3.70	.67	4.65	1.39	1.45	−1.54	17.31	2.11	114
Geneva, Experiment Station	3.99	1.25	3.80	.67	2.83	−.26	3.21	.20	.85	−1.97			
Syracuse, WBAS	2.60	−.52	2.88	−.02	4.18	.50	6.13	2.87	3.45	.36			
CONNECTICUT													
Northwest	4.38		2.47		1.86		2.83		2.66		14.20		
Cream Hill	3.46	−.17	2.27	−1.71	1.58	−2.64	3.24	−1.32	2.92	−1.45	13.47	−7.29	65
Central	4.52		2.15		1.29		2.36		3.08		13.40		
Storrs	4.10	.54	1.59	−1.91	.75	−2.42	2.31	−1.91	4.25	.09	13.00	−5.61	70
Coastal	4.70		2.83		.71		2.21		3.29		13.74		
New Haven WBAS	4.62	.73	2.75	−1.12	.96	−2.85	1.35	−2.31	2.95	−1.16	12.63	−6.71	65
MAINE													
Northern	2.16		2.09		3.11		4.32		2.13		13.81		
Caribou	2.57	−.06	1.62	−1.52	3.98	.03	6.83	2.80	.93	−2.60	15.93	−1.35	92
Jackman	2.37	−.56	3.08	−.28	2.76	−1.23	3.37	−.21	2.96	.10	14.54	−2.18	87
Southern Interior	2.37		2.95		3.26		3.83		1.40		13.81		
Farmington	2.06	−1.46	3.07	−.51	3.66	−.07	3.50	−.09	1.90	−1.81	14.19	−3.94	78
Woodland	3.62	−.17	2.86	.25	1.84	−1.32	4.00	1.54	3.00	−.12	15.32	.18	101

See footnote at end of table.

TABLE 2.—*Precipitation and its departure from normal*—Continued

	April 1957		May 1957		June 1957		July 1957		August 1957		5-month total		
	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Precip.	Dept.	Percent[1]
MAINE—Continued													
Coastal	2.73		2.60		2.18		2.56		1.94		12.01		
Bar Harbor	3.88	.13	2.74	−.61	1.74	−1.53	2.57	−.79	2.67	−.58	13.60	−3.38	80
MASSACHUSETTS													
Western	2.98		4.10		3.11		3.88		2.37		16.44		
Pittsfield, WBAS	2.69	−.92	4.09	.33	2.91	−1.68	3.03	−1.92	3.02	−1.29	15.71	−5.48	74
Central	3.19		3.46		2.39		1.16		1.61		11.81		
Fitchburg	3.13	−.92	3.16	−.32	2.50	−1.09	.46	−3.31	1.29	−2.63	10.55	−8.27	56
Springfield, Armory	4.48	1.18	2.96	−.76	1.17	−2.61	3.51	−.76	1.10	−3.14	13.22	−6.09	68
Coastal	3.78		2.12		.72		1.81		3.34		11.77		
Brockton	4.39	.91	1.86	−1.08	.58	−2.45	.75	−2.88	2.15	−1.30	9.73	−6.80	59
Nantucket, WBAS	2.67	−.78	1.46	−1.45	.26	−2.98	2.84	.01	4.19	.76	11.42	−4.44	72
NEW HAMPSHIRE													
Northern	2.15		3.46		3.97		5.86		1.36		16.80		
Bethlehem	1.03	−1.60	3.73	.88	3.91	.25	5.36	1.32	.71	−2.78	14.74	−1.93	88
First Connecticut Lake	2.67	−.72	3.70	−.18	4.42	.05	7.60	2.75	2.50	−1.62	20.89	.28	101
Southern	1.94		3.08		3.09		1.25		1.53		13.41		
Keene	2.23	−.86	4.14	1.03	2.23	−1.00	2.32	−1.48	1.11	−2.75	12.03	−5.06	70
Lakeport	2.02	−1.38	3.32	.11	3.93	.60	3.44	−.45	1.34	−2.20	14.05	−3.32	81
RHODE ISLAND	4.32		1.72		.66		1.25		3.52		11.47		
Kingston	4.34	−.29	1.99	−1.87	.12	−3.34	1.46	−1.88	4.60	.30	12.51	−7.08	64
VERMONT													
Northeastern	1.88		3.17		4.64		4.83		1.23		15.75		
Chelsea	1.72	−1.07	3.51	.49	4.75	1.41	4.44	.98	1.23	−2.20	15.65	−.39	98
Newport	2.79	−.15	3.33	.26	4.07	.64	5.36	.97	1.62	−1.37	20.05	.35	102
Western	2.04		3.50		5.13		4.21		1.42		16.30		
Burlington WBAS	2.11	−.52	2.95	.06	7.35	3.78	5.34	1.59	.72	−2.29	18.47	2.62	117
Rutland	1.71	−1.40	3.45	.06	3.81	−.13	4.78	.85	2.92	−.68	16.67	−1.30	93
Southeastern	2.47		3.62		3.80		3.62		1.31		14.82		
Somerset	3.60	−1.07	4.63	.46	6.27	1.88	5.32	.76	1.53	−2.78	21.35	−.75	97

[1] Percent of 5-month long-term mean.

and cooperating observers from Virginia to Maine is shown in table 2. The monthly averages and departures for the various climatological divisions are based on all reports within the division. In the States of New England and in Pennsylvania and West Virginia, the monthly long-term means are not yet available for the climatological divisions shown. In those areas no division monthly departures can be computed.

A close inspection of table 2 will convince one that the worst of the moisture deficiency occurred in the coastal strip from inner Cape Cod to the Virginia Capes—in agreement with figure 2. In Virginia the Eastern Piedmont and Tidewater sections received, generally speaking, the least rainfall. Western Maryland was spared the worst of the drought, but the rest of the State and Delaware suffered. In New York the rainfall pattern was such that the southeastern part received the least, along with eastern Pennsylvania and nearly all of New Jersey where for the State as a whole, the May through July rainfall was the lowest on record (back to 1866). The southeastern half of New England also endured a severe shortage of rainfall.

An overall picture of the 5-month period is shown in figure 3 which presents the total 5-month average precipitation over each of the climatological divisions in terms of percentage of the 5-month long-term mean. This map is based on the totals in table 2. In those States where division long-term means are not yet available, the percentage for individual stations has been used and the isopleths in figure 3 were smoothed somewhat subjectively.

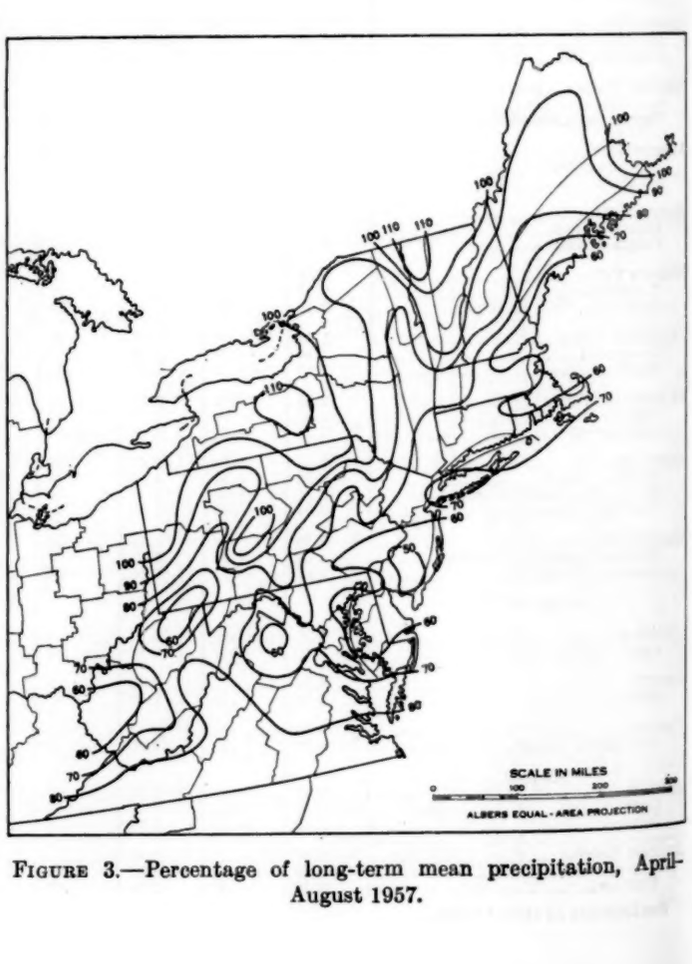

FIGURE 3.—Percentage of long-term mean precipitation, April-August 1957.

While this procedure is not entirely satisfactory, it seems the best that can be done under the circumstances.

The data shown in tables 1 and 2 and figures 1 and 3 represent the "high road" approach to drought, and it is apparent that though a picture of the drought situation can be gleaned from these data, it is not a picture that is very distinct and is not at all amenable to comparison with other droughts at other times and places.

4. STREAMFLOW AND GROUND WATER

Another way of looking at the drought is to examine its effect on streams, reservoirs, and well-levels. In April 1957, runoff and streamflow were deficient over most of New York and New England, except in their southern fringes. Ground-water levels reached record-low stages for the month at key wells in Maine, New Hampshire, and Vermont. Over the rest of the Northeast (including Virginia) the water situation was generally satisfactory.

In May, however, practically the entire Northeast, particularly New England, suffered from deficient streamflow. Runoff was subnormal in New England, southern New Jersey, and Maryland. "Ground-water levels generally declined and were below average except in western New York and northwestern Pennsylvania. Record-low levels for May were observed in wells in Maine, New Hampshire, Massachusetts, and Connecticut." [3] Deficient runoff, below-average reservoir storage, and very low ground-water levels also characterized the Northeast in June; many New England wells reached record-low levels for the month.

July brought some improvement, but the coastal area continued in poor condition. Streamflow was about median in Maine, but reservoir storage was considerably below average and ground-water levels mostly subnormal. Runoff ranged from excessive in northern Vermont to greatly deficient in southeastern Massachusetts and Rhode Island. Ground-water levels in Rhode Island, Massachusetts, and southern New Hampshire declined to below average; in some wells they were record-low for July. Connecticut streams were at or near record-low flows. Southeastern New York also remained in the drought area. Streamflow and well-levels in New Jersey continued to decline, especially in the southern half of the State. The other Northeastern States, except "upstate" New York and western Pennsylvania, also experienced deficient streamflow and low ground-water levels. In August, runoff was deficient over most of the Northeast, south of Maine. Ground-water levels remained below average and were at or near record-low stages in southern New England. In Connecticut, the key station on the Quinebaugh River at Jewett City set a new runoff low in its 40 years of record, 20 percent lower than in October 1930, the previous minimum month of record. The key station, Great Egg Harbor River, at Folsom, N. J., with 32 years of record, had record-low runoff for the second consecutive month. Though late-August rains [4] alleviated the agricultural drought in many sections, they had little effect on runoff or ground-water recharge.

Thus, the hydrologic aspects confirm the same general picture of summer drought, most intense and of record-breaking character along the southern New England and Middle Atlantic Coasts.

5. CROP CONDITIONS

The best measure of agricultural drought, if an adequate network of measuring stations were available, would be that furnished by regular, standardized measurements of soil moisture. In the absence of such data, it has been necessary to consider the subject by the previous indirect approaches. Since some soil moisture conditions are reported in the Northeast, it is possible to make some attempt to attack the situation directly.

In all the States involved, the Weather Bureau and the Agricultural Marketing Service of the U. S. Department of Agriculture (in some cases with the cooperation of other Federal or State agencies) join in issuing weekly weather and crop reports. Much of the information collected in these publications comes from county agents and actual growers, and from such sources as these, the development of the drought during the past summer can be reconstructed. This development is summarized, by States, in the following paragraphs; unless otherwise indicated the quoted remarks were taken from the weekly reports issued for the respective State.

New England.—In New England, after a mid-April to mid-May dry spell, the beginning of June found moisture supplies fairly adequate and crop development ranging from good to excellent, except in some very dry localities mostly in Rhode Island, southeastern Massachusetts, and eastern Connecticut. A month later, though the three northern States had benefited from rainfall, southern New England was gripped by drought. In mid-July it was reported that "severe dry weather continues to damage non-irrigated crops in eastern Massachusetts, eastern Connecticut, and Rhode Island." Widespread showers toward the end of July helped some sections but "much more rain is badly needed throughout most of the area." Conditions improved slowly during August, and on September 3 it was noted that in northern New England, potatoes, corn, and vegetables "had about completed growth under generally favorable conditions"; while in the southern part "The drought has been quite generally relieved and most crop prospects have improved markedly."

New York.—There was also an early-season drought general throughout New York State, but about May 10–13 it was broken upstate by bountiful rains, and this area was thereafter spared the worst. Downstate, however, dry weather continued and intensified; on June 24 it was reported that "dry soil conditions are becoming more serious in several southeastern counties and on Long Island." A month later (July 29) this observation was made: "Crops generally continued to make satisfactory to good growth except for the Hudson Valley area and Long Island where dry soil conditions have seriously affected

pastures and some crops." By August 19, "drought conditions continued to increase in the more eastern counties and moisture deficiency is beginning to show in some western counties." Some rainfall during the latter part of the month gave spotty relief, but as late as September 9 soils were still dry in many locations.

New Jersey.—During April, New Jersey had generally ample soil moisture, but this was greatly reduced over the next two months. It was reported on July 8 that the "soil moisture deficiency is becoming more serious" and that "near-drought conditions prevail in central and southern counties, and in some counties of northern New Jersey." These conditions deteriorated during July and August; a general rain on August 25–26 was "the first in the State since early April."

Pennsylvania.—Though the latter half of April in Pennsylvania was wet, May went to the other extreme, and as June began, soil moisture was generally below normal. This month brought rain, so that on July 1 it was noted that "soil moisture is generally adequate." During the next three weeks, however, rainfall was deficient, and on the 22d the report read: "In some sections of the Southeast most crops are beginning to show signs of drought conditions, particularly hay fields and pastures." This situation grew worse; by August 12, crops throughout most of Pennsylvania were in urgent need of rain, with drought prevailing in the majority of the southeastern counties. On September 9 it was still noted that "dry conditions prevail throughout most of the State and crops are in generally poor condition."

Maryland and Delaware.—Lack of soil moisture was in evidence in southern Maryland and the Eastern Shore as early as May 7. On the 13th, this was stated: "Three successive weeks of sparse rainfall in combination with above-average temperatures spread drought throughout Maryland and Delaware. At the end of this week soils were reported 'dry' to 'very dry', with the moisture situation in the southern portion of the two-State area considered to be more critical than elsewhere." On June 4 soil moisture was considered about "normal" by crop and weather reporters only in north-central and western Maryland and the extreme northern portion of the Eastern Shore. During June, July, and August (up to the 25th) soil moisture decreased as the drought entered its critical phase. Except for corn, most crops responded rather well to the late-August rains; but as late as September 10 more rain was still needed to revive pastures which on September 1 "were in poorest condition ever recorded in Delaware for that date and in Maryland . . . were the poorest of record except for 1930."

Virginia.—When the growing season opened in Virginia, there was adequate soil moisture, but this "was rapidly depleted April 16–May 15, during which time very little rainfall was recorded especially over the Piedmont and Tidewater portions of the State." [1] From mid-May through early June, above-normal rainfall returned soil moisture to satisfactory levels for most crops. Then came the worst period, mid-June through mid-August, when "moisture demands by crops exceeded available supplies earliest in the Tidewater and Eastern Piedmont sections, spreading to the Northern and the Central Mountain areas during July and early August, while becoming more severe in the eastern half of the State." [1]

West Virginia.—Soil moisture in West Virginia was "generally adequate" in early June after an early-May dry spell. By the first week of July, soil moisture was "becoming in short supply over much of the State." It was reported "acutely short" on July 19, with "most of the State suffering from drought conditions." Rains during the week of the 22–26th helped the situation somewhat, but on August 9 soil moisture was "becoming critically short." On August 30 it was noted that "farm crops are suffering severely from lack of soil moisture and many farmers are forced into early feeding or sale of their livestock. Pastures are burned badly and are furnishing very little forage . . . Although dry conditions are predominant, there are a few scattered areas that have had a good growing season." The drought was still continuing through early September.

TABLE 3.—*Plant-available water in soil and deficit (inches),* [1] *Upper Marlboro, Md. Monmouth fine sandy loam. Fescue sod*

Date		Depth (inches)					Precipitation past week (inches)
		0-6	6-12	12-24	24-36	Total	
Apr. 10	Available	1.4	1.3	2.5			
	Deficit	.1	.3	.4			
18	Available	1.0	1.2	2.5			0.17
	Deficit	.5	.4	.4			
24	Available	.7	1.1	2.4			
	Deficit	.8	.5	.5			
May 1	Available	1.0	[3]1.7	2.0			[3].75
	Deficit	.5	[3].9	.9			
8	Available	.4	[3].7	1.6	1.9	4.6	
	Deficit	1.1	[3].9	1.3	.9	4.2	
15	Available	.3	[3].4	1.3	2.0	4.0	.30
	Deficit	1.2	1.2	1.6	.8	4.8	
22	Available	.5	.4	1.3	1.7	3.9	.74
	Deficit	1.0	1.2	1.6	1.1	4.9	
29	Available	.2	.4	1.3	1.6	3.5	
	Deficit	1.3	1.2	1.6	1.2	5.3	
June 6	Available	1.4	.8	1.0	1.5	4.7	2.22
	Deficit	.1	.8	1.9	1.3	4.1	
12	Available	.7	.8	1.3	1.1	3.9	.08
	Deficit	.8	.8	1.6	1.7	4.9	
19	Available	.5	.4	.9	1.0	2.8	1.29
	Deficit	1.0	1.2	2.0	1.8	6.0	
26	Available	.8	.4	.8	.7	2.7	1.07
	Deficit	.7	1.2	2.1	2.1	6.1	
July 3	Available	0	.3	.9	.6	1.8	.17
	Deficit	1.5	1.3	2.0	2.2	7.0	
10	Available	0	.2	.6	.5	1.3	.18
	Deficit	1.5	1.4	2.3	2.3	7.5	
17	Available	−.1	.2	.5	.5	1.1	
	Deficit	1.6	1.4	2.4	2.3	7.7	
24	Available	.4	0	.5	.5	1.4	.51
	Deficit	1.1	1.6	2.4	2.3	7.4	
31	Available	−.1	.1	.5	.6	1.1	.02
	Deficit	1.6	1.5	2.4	2.2	7.7	
Aug. 7	Available	−.1	0	.2	.4	.5	.13
	Deficit	1.6	1.6	2.7	2.4	8.3	
14	Available	−.1	.1	.5	.3	.8	.04
	Deficit	1.6	1.5	2.4	2.5	8.0	
21	Available	.1	0	.3	.5	.9	.30
	Deficit	1.4	1.6	2.6	2.3	7.9	
28	Available	.7	.6	.6	.3	2.2	1.95
	Deficit	.8	1.0	2.3	2.5	6.6	
Sept. 4	Available	.8	.6	.8	.4	2.6	1.00
	Deficit	.7	1.0	2.1	2.4	6.2	
11	Available	1.0	.7	.7	.5	2.9	1.13
	Deficit	.5	.9	2.2	2.3	5.9	
18	Available	1.2	1.2	1.7	.7	4.8	3.13
	Deficit	.3	.4	1.2	2.1	4.0	

[1] Available moisture based on 15-atmosphere wilting point determinations made in September 1957.
[3] Irrigation.

[1] Special communication from Kenneth A. Rice, State Climatologist.

TABLE 4.—*Soil moisture conditions in New Jersey, early August 1957*

Location	Crop	Soil type	Depletion Depth (inches)
NORTHERN NEW JERSEY			
Newton, Sussex County	Alfalfa	Dutchess loam	18
Sparta, Sussex County	Alfalfa-orchard grass.	Dover loam	18
Stockholm, Sussex County	Clover	Gloucester gravelly loam.	36
Hackettstown, Warren County	Soybeans—sorgo	Washington loam	18
Butler, Morris County	Woods	Gloucester gravelly loam.	36
Hibernia, Morris County	Corn	Merrimac sandy loam	30
Lake Hopatcong, Morris County	Woods	Rockaway loam	26
Gladstone, Somerset County	Orchard grass	Anandale loam	24
Martinsville, Somerset County	Vacant field (woods).	Montalto loam	9
Jamesburg, Middlesex County	Rhubarb	Spotswood loam	54
Plainsboro, Middlesex County	Woods	Spotswood loam	0
Marlboro, Monmouth County	Sweet corn	Freehold sandy loam	24
Hightstown, Mercer County	Abandoned orchard.	Spotswood sandy loam.	36
Pennington, Mercer County	Abandoned field (weeds).	Penn silt loam	30
Washington's Crossing, Mercer County.	Corn	Lansdale loam	0
SOUTHERN NEW JERSEY			
Beverly, Burlington County	Woods	Evesboro sand	60+
Mount Laurel, Burlington County.	Soybeans—sorgo	Collington sand	30
Pemberton, Burlington County	Alfalfa	Collington sandy loam.	42
Berlin, Camden County	Asparagus	Evesboro sandy loam	0
Haddonfield, Camden County	Alfalfa	Collington sandy loam.	36
Glassboro, Gloucester County	Apples	Keansburg sandy loam.	36
Swedesboro, Gloucester County	Corn	Sassafras sandy loam	18
Alloway, Salem County	Corn	Keyport loam	12
Palatine, Salem County	Corn	Aura loamy sand	42
Penns Grove, Salem County	Asparagus	Sassafras loamy sand	0
Bridgeton, Cumberland County	Corn	Downer loamy sand	36
Leesburg, Cumberland County	Tomato	Sassafras loamy sand	0
Woodbine, Cape May County	Woods	Sassafras sand	42

6. SOIL MOISTURE

At a number of locations in the drought area, measurements of soil moisture were taken and afford invaluable information both for their own sake as well as for the light they shed on the other drought indicators. The Tobacco Experiment Farm of the College of Agriculture, University of Maryland, situated at Upper Marlboro, Md. (about 15 miles southeast of downtown Washington, D. C.) was in one of the worst-affected areas. On May 8 (see table 3) the top 6 inches of soil was found by gravimetric sampling to be near the wilting point. This continued through the month and on May 29 there was only 0.6 inch of available water in the top 12 inches. During July and early August there were very low or "negative moisture" values, indicating the soil to have been dried to near or below the permanent wilting point at all levels down to the lowest measured (3 feet). This condition persisted into early September, with some improvement in the upper layers toward the end of the period.

The data from a series of gravimetric soil moisture measurements [2] made in New Jersey under representative crops are presented in table 4, according to the "depletion depth." By this is meant the soil depth to which the soil moisture was found to be depleted to the permanent wilting point or below. The 60+ figure results from the fact that no samples were taken below a depth of 60 inches. The zero values indicate that some moisture existed at all levels sampled, even though soil moisture may have been very close to the wilting point. Of course, samples could only be made down to shallower depths than 60 inches in those cases where the underlying parent material was reached first. In general, the soils are much shallower in northern than in southern New Jersey. Consequently, it cannot be concluded from the fact that the greatest depletion depths are shown in southern locations that the drought was not as severe or even more severe in the north. For example, at Newton, solid rock was reached at only 18 inches, which had to be reported as the depletion depth; but from the point of view of growing crops the conditions at these sites may have been more severe than, say, the 24-inch depletion depth at Marlboro, N. J.

In Rhode Island a series of soil moisture measurements have been taken at Kingston [3] during the summer and are summarized in table 5. These data indicate a very serious shortage of soil moisture developed late in June,

TABLE 5.—*Percent of available moisture, Kingston, R. I. Narragansett loam. Pasture plot*

Date	Depth (inches)			
	4	8	12	24
	(Percent)	(Percent)	(Percent)	(Percent)
June 7	36	38	47	78
14	28	29	37	76
28	13	11	11	34
July 5	4	1	0	13
12	3	0	0	9
19	0	0	0	8
26	35	0	0	9
Aug. 1	29	0	1	13
8	56	52	0	16
19	53	63	43	28
26	78	81	49	58
Sept. 6	25	45	49	72

TABLE 6.—*Plant-available water in soil and deficit (inches), Windsor Conn. Merrimac sandy loam. Shade tobacco*

Date		Depth (inches)	
		0-6	6-11
June 21	Available	0.76	
	Deficit	0.21	
28	Available	0.87	
	Deficit	0.10	
July 5	Available	0.82	
	Deficit	0.15	
12	Available	0.75	0.92
	Deficit	0.22	[1]—0.10
19	Available	0.50	0.66
	Deficit	0.47	0.16
25	Available	0.59	0.68
	Deficit	0.38	0.14
Aug. 2	Available	0.82	0.97
	Deficit	0.15	[1]—0.15
8	Available	0.49	0.71
	Deficit	0.48	0.11
15	Available	0.47	0.59
	Deficit	0.50	0.23
23	Available	0.44	0.50
	Deficit	0.53	0.32

[1] Negative deficit indicates amount above field capacity.

[2] The New Jersey measurements were made by Dr. N. A. Willits, Associate Professor of Soils, New Jersey Agricultural Experiment Station, Rutgers University; his courtesy in making them available for this article is appreciated.

[3] The Rhode Island soil moisture measurements are furnished through the courtesy of Dr. R. C. Wakefield, Associate Professor, Agronomy Department, Rhode Island Agricultural Experiment Station.

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reached its maximum in mid-July, and remained quite serious until about mid-August. However, the Connecticut data [4] in table 6 do not indicate as intense or as prolonged moisture shortages under the "shade tobacco" conditions as under the pasture conditions at Kingston.

In both States crops deteriorated rapidly after mid-June and did not show any recovery until rainfall in late July brought some relief to portions of southwestern Connecticut. The eastern counties of Connecticut and Rhode Island continued very dry, and wells, streams, and ponds, never in memory dry before, dried up. Farmers were forced to haul water for livestock and other uses and barn feeding of livestock was necessary as pastures for the most part failed to provide any significant grazing. The first general rain in 3 months occurred on August 25–26 to put soil in the most favorable moisture condition since May.

7. CONCLUSION

The above material may be summarized as follows:

A. The Eastern drought primarily affected the coastal strip from southeastern Massachusetts, Rhode Island, and Connecticut, through southern New York, New Jersey, and eastern Pennsylvania, to Delaware, Maryland, and eastern Virginia. In general, conditions were less severe in the interior, though West Virginia and some other inland areas appear to have been hurt badly.

B. The drought began in mid-April; April 10 is frequently cited in the reports as the beginning of the dry spell. This was not too harmful agriculturally, because of the early stage of most crops, and because it was alleviated in several areas by late-May rains. The important months of June and July, however, defined the worst drought area (as just described), and most of August intensified it. Good rains came to many areas in late-August and early-September (especially noteworthy being the August 25–26 coastal storm [4]), but many localities continued to suffer from deficient moisture throughout.

C. The period of mid-June to mid-August may be taken, from both the climatological and the agricultural viewpoints, as the worst phase of the drought. The map of moisture deficiency represents conditions during this period fairly well, except in West Virginia. The evidence of the map is well supported by the rainfall figures and the streamflow and ground-water data. The reports of crop conditions, in general, bear out very well the conclusions regarding the duration and areal extent of the drought. If more soil moisture measurements were available, in addition to those cited, it would be possible to speak with more certainty regarding these points.

D. From the climatological and hydrologic standpoints, the drought was rather severe. The fact that so many Weather Bureau stations reported new record-low rainfall during the period, plus the near-record or record-breaking character of much of the streamflow data, indicate that, for the region affected and the time of year, it may be considered as unprecedented in some areas. Two qualifications must be quickly added to this blanket statement. The drought did not affect all parts of the Northeast equally, and some places may have been troubled by it scarcely at all. On the other hand, even in the badly-hit areas, some localities may have been more grievously affected in the past. The second qualification is this: no precise evaluation of the drought in strictly agricultural terms is here attempted.

E. The severity of drought depends on both the magnitude of the moisture deficiency and its duration. This drought in the East during the spring and summer of 1957 was without doubt very intense during these few months but its severity is hardly comparable with many other droughts which have affected other areas of the United States in the past—droughts in which the duration was measured in years rather than months [5].

[4] The Connecticut soil moisture data are furnished through the courtesy of Dr. H. C. De Roo, Associate Soil Scientist, Windsor Tobacco Laboratory, Connecticut Agricultural Experiment Station.

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THE WEATHER AND CIRCULATION OF SEPTEMBER 1957[1]

Including a Discussion of Tropical Storm Activity

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1. COMPARISON WITH THE SUMMER MONTHS

The weather and circulation of the past summer was marked by extreme heterogeneity. The month of June was characterized by a mean trough through the central part of the United States with ridges along each coast [6]. A marked reversal in circulation characteristics took place between June and July [5] as a pattern more typical of summer emerged with a trough off each coast and a ridge over the Great Plains. The sharp circulation reversal from June to July was followed by strong persistence from July to August at middle latitudes of the Western Hemisphere [4].

The circulation experienced yet another oscillation in its transition from August to September. The planetary wave train became remarkably akin to that of June 1957 [6], with a trough again in the middle of the United States and the coastal troughs of July and August supplanted by ridges (fig. 1). The reappearance of the mid-continental trough was suggested during the latter half of August (15-day mean, not shown), when the east coast trough fractured, with the southern portion retrograding toward the lower Mississippi Valley.

Despite the large changes in hemispheric circulation observed from August to September (fig. 2A), blocking was still an important feature of the circulation. The block that had been dominant in the western Canada-Alaska area for the previous three months became a strong ridge along the west coast of Canada, appearing as a closed High on many of the 5-day mean maps (fig. 3). Blocking re-emerged in the Greenland area and in the Bering Sea, where 700-mb. heights were 320 feet above normal and sea level pressures (Chart XI, inset) 7 mb. above normal. The high latitude block over Siberia in August [4] moved southwestward into western Siberia, and the deep polar vortex of August filled greatly as the polar region became a seat of above normal heights.

Persistence from August to September, while climatologically not quite as marked as from July to August [7], is usually much stronger than it was this year (table 1). The −0.29 lag correlation of 700-mb. height anomalies over the United States is an indication of the reversal that took place. The lack of persistence in the circulation was reflected in large-scale changes in temperature and precipitation. Only 56 of 100 stations in the United States changed temperature by one class or less compared with a normal of 72; similarly, fewer than normal stations (20 instead of 35) remained in the same precipitation class (last line of table 1). Part of the associated reversal in weather regime (figs. 2B and 2C) can be interpreted in terms of the changes in 700-mb. height anomalies from August to September (fig. 2A).

2. MONTHLY MEAN CIRCULATION AND WEATHER

The fairly well-defined temperature and precipitation patterns for the month of September (Charts I–B, II, and III–B) can be related quite well to the monthly 700-mb. height and height anomaly patterns (fig. 1), despite the changes in these patterns which took place during the month (section 3). Temperatures as much as 5° F. above normal occurred in the Pacific Northwest and along the California coast under anticyclonic conditions, above normal heights, and abundant sunshine (Chart VII). The warm temperatures in the Pacific Northwest during September represented an extremely sharp reversal from the cool weather experienced there during August (fig. 2B). This warmth was a consequence of upper-level ridge development along the coast (fig. 2A) and frequent anticyclonic passages in the vicinity of the Rockies (Chart IX) which kept the Northwest mainly in dry southerly flow at sea level. Warming was also experienced along the east coast, largely as a result of anticyclonic conditions off the coast (figs. 1 and 2A).

The area from the Rockies to the Appalachians was cool (Chart I–B) as a consequence of frequent intrusions of polar Canadian anticyclones (Chart IX). These anticyclones were steered rather well by the mean 700-mb. flow from the northwest. This area was one of below normal 700-mb. heights and cyclonic flow at 700 mb. Northerly anomalous flow from the Rockies to the Missis-

TABLE 1.—*Persistence measures of monthly mean anomalies in the United States from August to September*

	1957	Normal*	Random
700-mb. height (lag correlation)	−0.29	+0.33	0.00
Temperature (0 or 1 class change, percent)	56	72	60
Precipitation (0 class change, percent)	20	35	33

*Normal persistence measures of 700-mb. height based on 1933–1950 data, temperature on 1942–1954 data, and precipitation on 1942–1950 data.

[1] See Charts I–XVII following p. 328 for analyzed climatological data for the month.

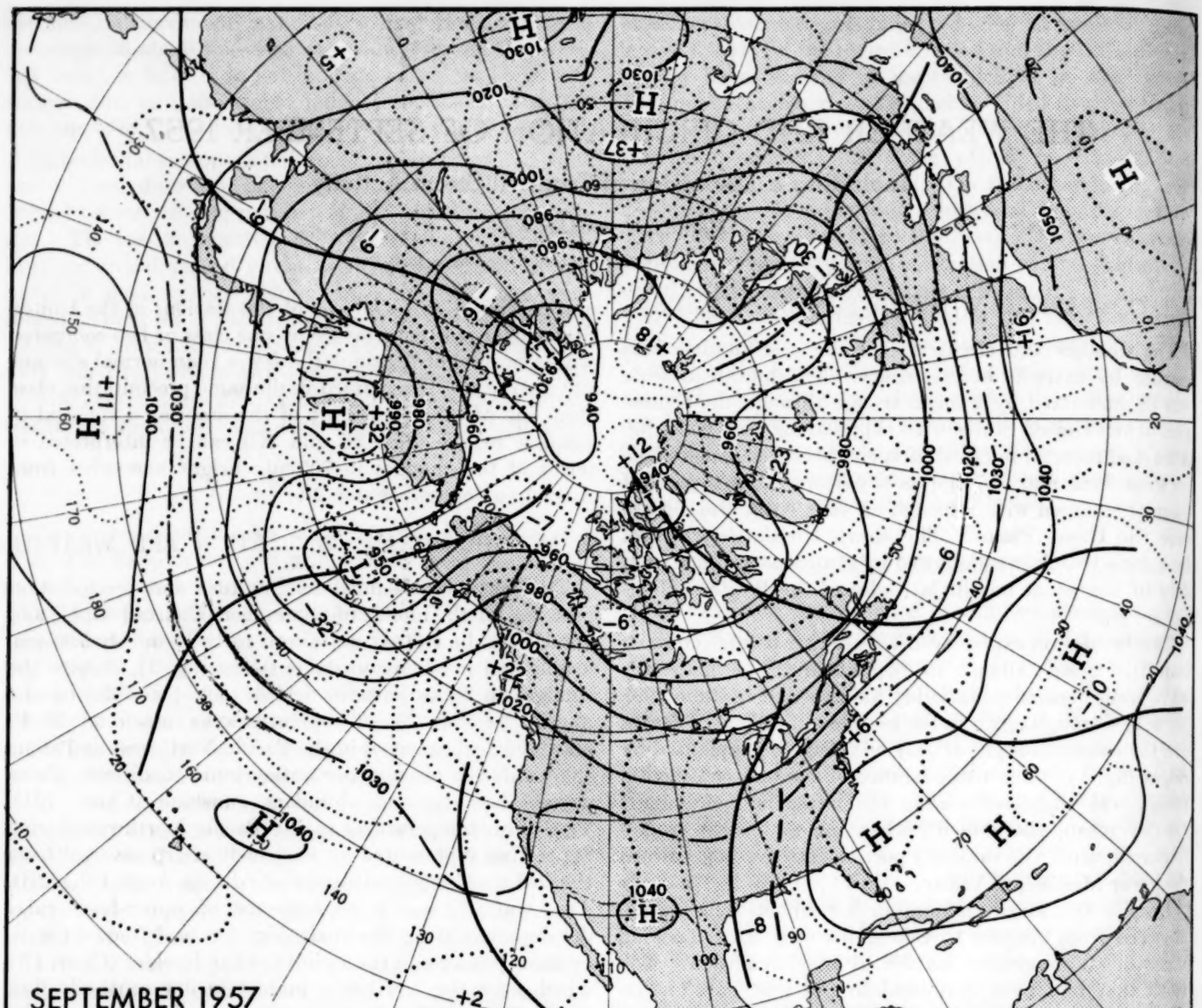

FIGURE 1.—Mean 700-mb. contours (solid) and height departures from normal (dotted), both in tens of feet, for September 1–30, 1957. Troughs for September are indicated by heavy vertical lines; position of trough in the Southeast in the period mid-August to mid-September is indicated by a heavy dashed line. Dominant feature in the United States was the mean trough in the Mississippi Valley.

sippi contributed to cool temperatures—averaging as much as 6° F. below normal in Wichita, Kans. The carving out of the trough in the Mississippi Valley is evident on the anomalous change chart (fig. 2A), and the more northerly flow lowered temperatures by 2 classes (fig. 2B) in the area to the west of the Mississippi. The lowering of temperatures along the Gulf coast and in part of the Southeast, despite increased southerly flow, was partly the consequence of less sunshine than normal and many rainy days (table 2 and Chart VII), as record and near record precipitation fell in many areas. (Charts II and III–B). This precipitation was influenced greatly by tropical storms plus abundant Gulf moisture moving inland.

TABLE 2.—*A sample of the effect of precipitation and cloudiness on temperature during September 1957*

Station	Days with precipitation	Amount of precipitation (inches)	Percentage possible sunshine*	Temperature anomaly (° F.)
Birmingham, Ala.	22	9.74	49	−1.3
Mobile, Ala.	21	13.61		−2.2
Pensacola, Fla.	21	15.15	36	−1.3
New Orleans, La.	26	10.90	36	−2.7
Jackson, Miss.	20	8.29	34	−3.4
Memphis, Tenn.	17	7.48	45	−2.3

*See Chart VII–B for percent of normal sunshine.

Record rainfall in the South did not spread far enough north to ease the droughty condition in parts of the Northeast. At Providence, R. I., which had the third driest September on record, total precipitation for the first 9 months of the year was less than 18 inches, the

least amount for that period in 125 years. A similar record was set in Boston, Mass., which had its driest 9 months in 140 years. The desiccation in parts of the Pacific Northwest and through the Plateau States (Albuquerque reported only a trace of rain for September) was the result of anticyclonic circulation and dry northerly anomalous flow aloft.

Temperatures along the California coast were warm despite record precipitation amounts recorded in many cities. The weather was prevailingly fair until the last few days of the month when a deep upper-level trough off the northern California coast brought moderate to heavy thundershowers with some hail to this area.

3. TRANSITION WITHIN THE MONTH

Unlike the relatively stationary wave pattern of July and August, September was characterized by change during the month (fig. 3). The first 3 weeks showed a steady retrogression of the major features of the circulation, followed by a rapid reversal in the fourth week. Concomitant with these permutations were changes in the temperature and precipitation regimes (figs. 4 and 5).

FIRST WEEK

In general, weekly temperatures averaged above normal from the Divide westward and from the Appalachians eastward, with below normal temperatures reported in the rest of the Nation (fig. 4A). Under a strong ridge (fig. 3A) temperature departures as large as +6° to +7° F. occurred in Montana and inland portions of southern California. Record maximum temperatures were observed in Helena, Mont. (92° F.), Las Vagas, Nev. (108° F.), and Red Bluff, Calif. (109° F. on Sept. 6 and 7). Las Vagas had 7 consecutive days with the temperature reaching or exceeding 100° F. Temperatures were above normal along the east coast as southerly flow prevailed east of the trough in the Mississippi Valley (fig. 3A). Record maximum temperatures for the date were established in Charlotte, N. C. (100° F.) and Columbia, S. C. (99° F.) on September 1.

Heavy precipitation in the extreme Pacific Northwest was the consequence of anomalous onshore flow of maritime Pacific air. A storm which developed in South Dakota on September 1 (Chart X) deepened rapidly on the 2d and 3d, and moved across the Northern Plains, accounting for the precipitation observed in that area during the week and, in fact, for a large share of the monthly total there. Its passage was followed by a series of cold outbreaks into the United States, with freezing temperatures reported in northern and central lowlands of Wisconsin on the 5th and subsequent dates and a reading as low as 23° F. in Cranmoor. New record minima were observed in such widely scattered cities as Erie, Pa., San Antonio, Tex., Indianapolis, Ind., and Grand Junction, Colo.

Perhaps the most important weather news of the month was hurricane Carrie which formed on September 2 and was in the headlines until its demise near western Europe

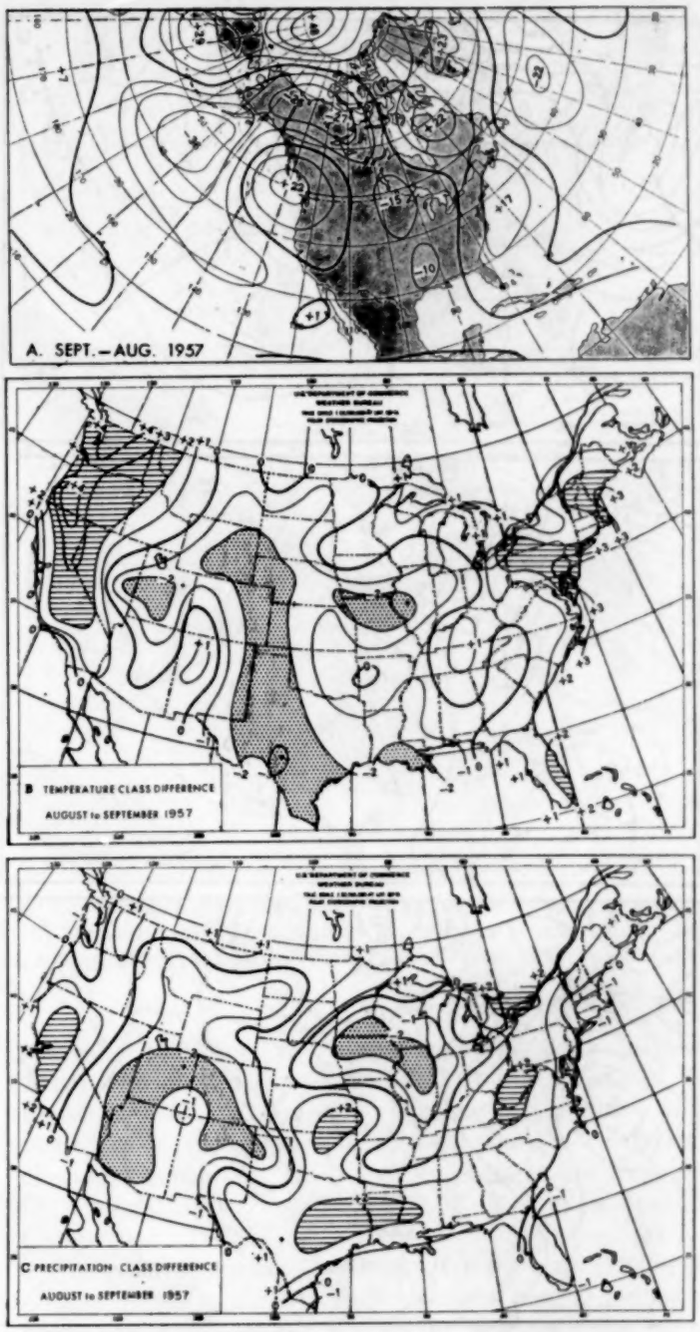

FIGURE 2.—Changes in monthly mean 700-mb. height departures from normal, August to September 1957. The isolines of anomalous height change (A) are drawn at 100-ft. intervals, with the zero line heavier and the centers labeled in tens of feet. A large reversal took place from August to September, as reflected in the number of classes the anomaly of temperature (B) and precipitation (C) changed. Increased values are considered positive and decreased values negative. Areas with increases of two or more classes are cross-hatched; areas with decreases of two or more classes are stippled.

on September 25 (fig. 6). More will be said about its development and subsequent motion in sections 4 and 5. Of more consequence to the weather of the United States was a weak tropical storm, Debbie, which formed in the central Gulf of Mexico on September 7 and moved north-

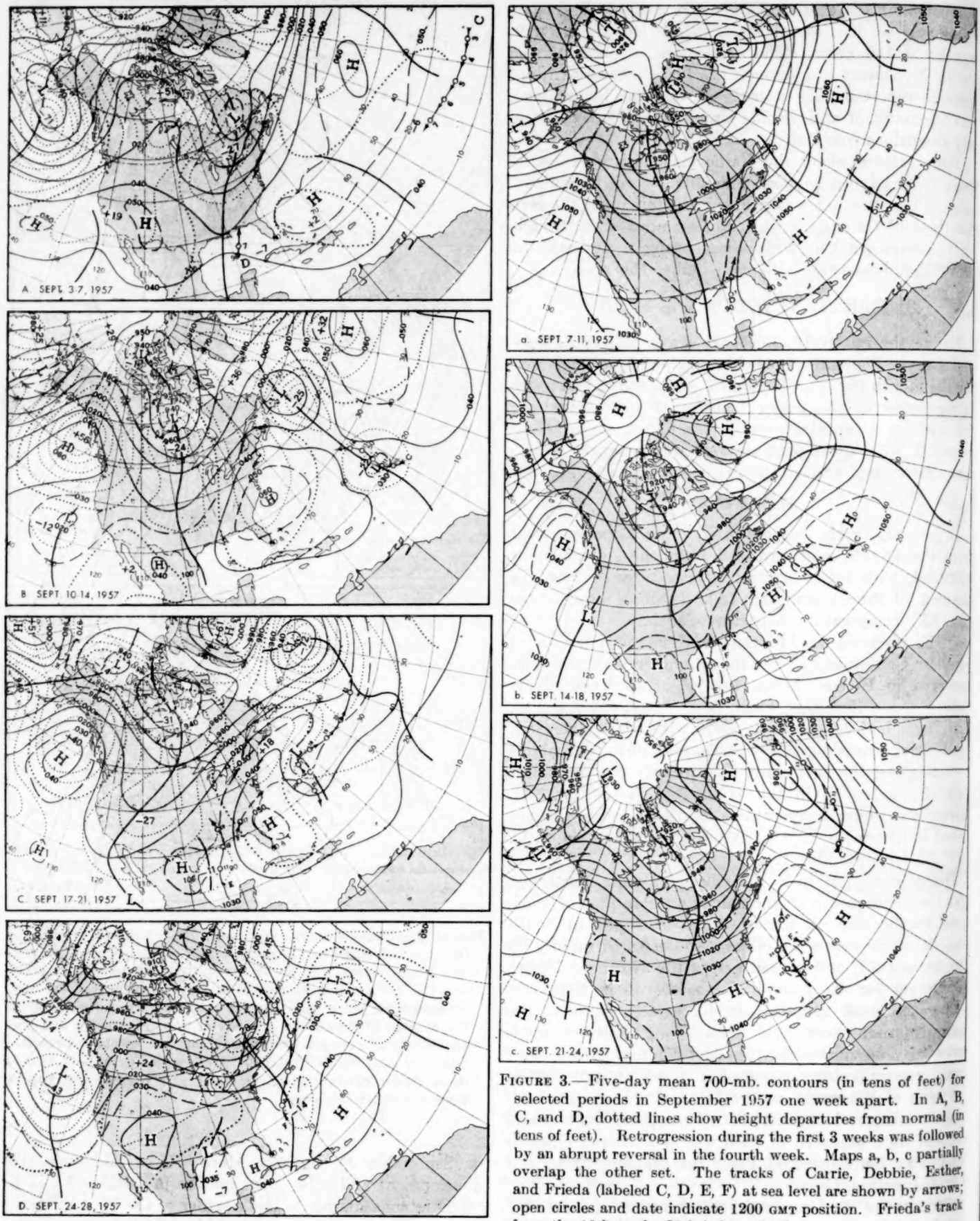

FIGURE 3.—Five-day mean 700-mb. contours (in tens of feet) for selected periods in September 1957 one week apart. In A, B, C, and D, dotted lines show height departures from normal (in tens of feet). Retrogression during the first 3 weeks was followed by an abrupt reversal in the fourth week. Maps a, b, c partially overlap the other set. The tracks of Carrie, Debbie, Esther, and Frieda (labeled C, D, E, F) at sea level are shown by arrows; open circles and date indicate 1200 GMT position. Frieda's track from the 16th to the 20th is hypothetical.

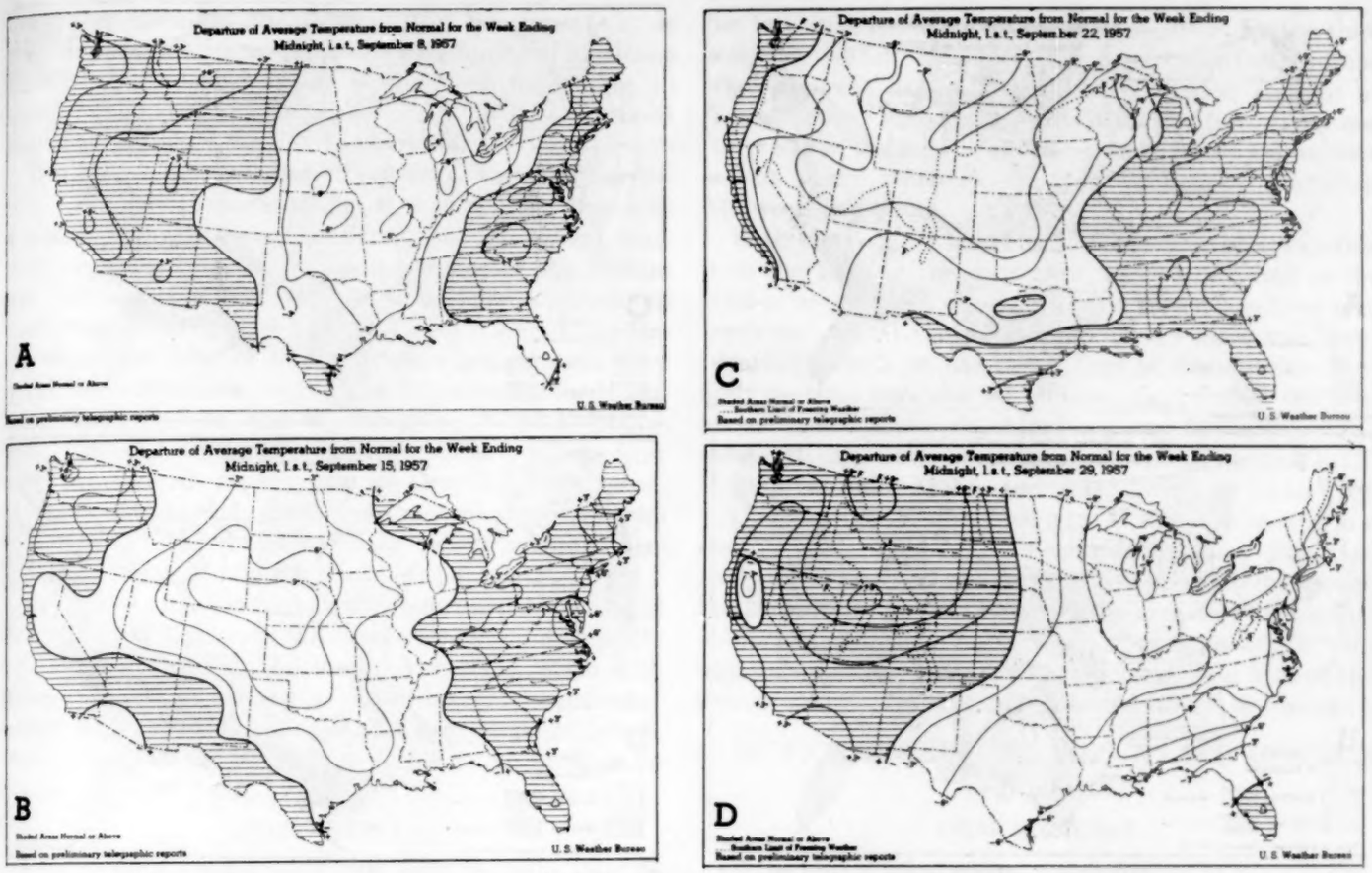
Departure of Average Temperature from Normal for the Week Ending
Midnight, l.s.t., September 8, 1957
A
Departure of Average Temperature from Normal for the Week Ending
Midnight, l.s.t., September 22, 1957
C
Departure of Average Temperature from Normal for the Week Ending
Midnight, l.s.t., September 15, 1957
B
Departure of Average Temperature from Normal for the Week Ending
Midnight, l.s.t., September 29, 1957
D

FIGURE. 4.—Departure of average surface temperature from normal (°F.) for weeks in September 1957, centered on the 5-day mean periods shown in the left column of figure 3, and ending (A) September 8, (B) September 15, (C) September 22, and (D) September 29. Retrogression of the pattern is discernible through the first three weeks, followed by a reversal. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLIV, Nos. 36–39, Sept. 9, 16, 23, and 30, 1957.)

eastward through northwestern Florida, southeastern Alabama, and Georgia. No casualties or severe damage were reported as the highest winds were about 40 m.p.h. with gusts up to 50 m.p.h. along the northwestern coast of Florida. Some flooding was reported due to heavy rain and high tides. Tides were as high as 4 feet above normal at the Panacea Coast Guard Station in northwestern Florida, and stations in that area had rain in excess of 9 inches. In general the precipitation associated with Debbie was about 2–4 inches, extending over an area from Florida to North Carolina (fig. 5A). The isohyetal pattern was typical of tropical storms, with the heaviest rainfall to the right of the storm's path.

SECOND WEEK

The retrogression that took place from the first to the second week is manifest in the 700-mb. map centered on the middle of the second week (fig. 3B) and the associated weather (figs. 4B and 5B), compared with that of the preceding week (figs. 3A, 4A, and 5A).

Above normal temperatures spread westward to the Ohio Valley, with the warmest temperatures along the east coast (fig. 4B). Temperatures were 7° F. above normal in Baltimore, Md.; and other cities along the mid-Atlantic seaboard reported temperature anomalies in excess of +5°. This area was under the influence of a strong ridge (with heights 200 feet above normal) and abundant sunshine. Record high temperatures were set in Boston, Mass., Providence, R. I., and New Haven, Conn.

The polar outbreaks continued over the central interior United States as the boundary of below normal temperatures retrograded to the west of the Rockies. Temperatures for the week averaged 10° F. below normal at Cheyenne, Wyo., Grand Island, and North Platte, Nebr. As the ridge in the west retrograded, the area of above normal temperatures diminished there. The largest temperature departure reported was +6° F. at Seattle, which had its highest temperature of the year on September 13.

West of the Continental Divide another rainless week continued the dry weather regime (fig. 5B). In Washington and Oregon dry weather combined with above normal temperatures and low relative humidity to intensify the extreme fire hazard, and logging operations were suspended in western Washington. Very little rain fell

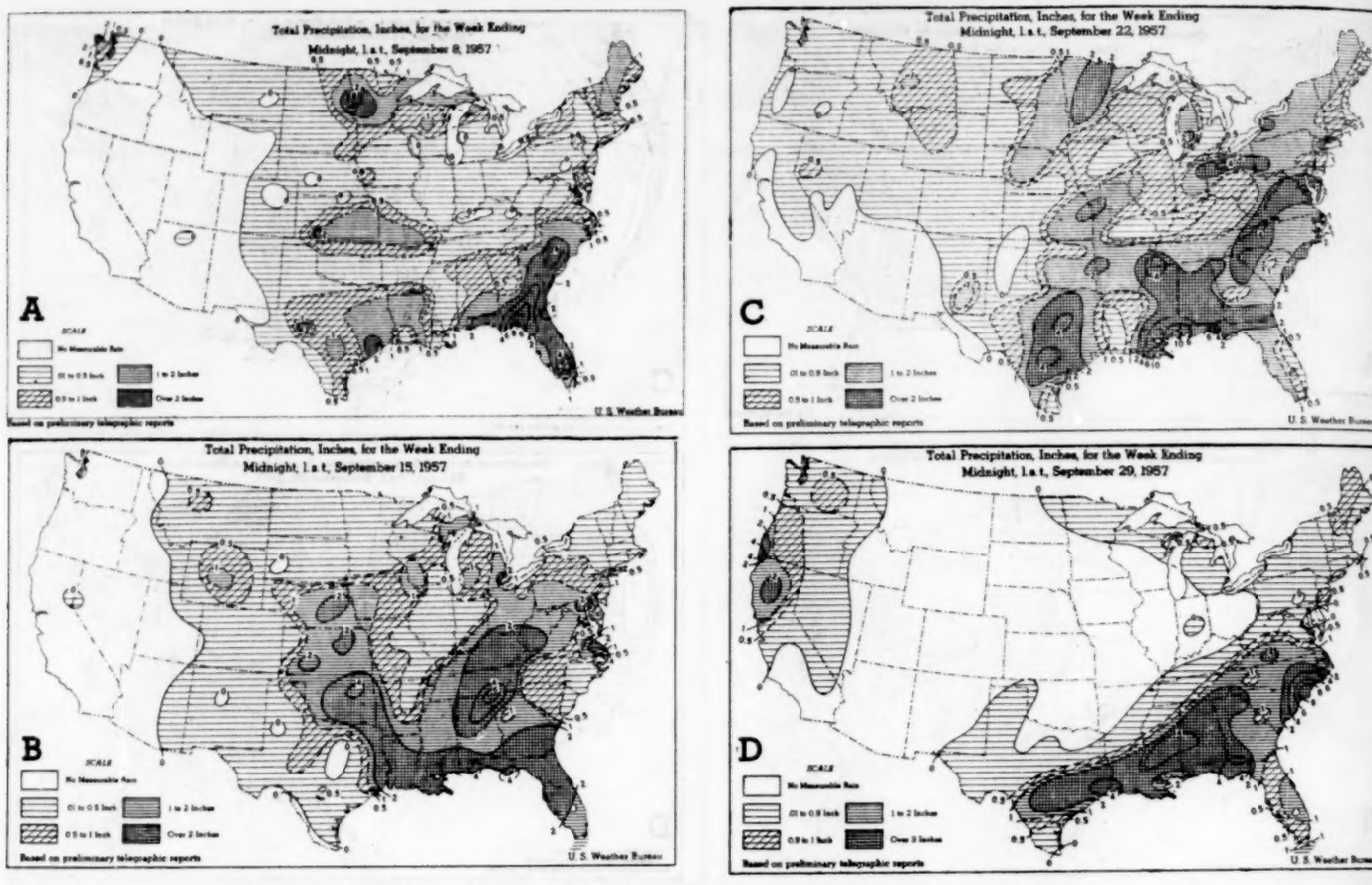
Total Precipitation, Inches, for the Week Ending
Midnight, l.s.t., September 8, 1957
A
Total Precipitation, Inches, for the Week Ending
Midnight, l.s.t., September 15, 1957
B
Total Precipitation, Inches, for the Week Ending
Midnight, l.s.t., September 22, 1957
C
Total Precipitation, Inches, for the Week Ending
Midnight, l.s.t., September 29, 1957
D
U.S. Weather Bureau

FIGURE 5.—Total precipitation (inches) for the same weeks and from the same source shown in figure 4. Heavy rain fell along the Gulf coast and in parts of the Southeast each week.

anywhere to the west of the United States trough, except for light precipitation in the Rockies, including snow in southern Wyoming and a 5-inch fall in Colorado. Moderate to heavy rains fell over the central Great Plains in an area of cyclonic circulation, with amounts exceeding 3 inches in Nebraska and Kansas. Heavy rain continued along the Gulf coast as deep tropical moisture was advected northward. A tongue of heavy precipitation extended northward on the windward side of the Appalachians into the Ohio Valley. More than 7 inches fell in Chattanooga, Tenn., partly in response to the remnants of Debbie. Thundershowers produced some small pockets of heavy rain along the mid-Atlantic coast. But a large portion of this area, especially New England, experienced light precipitation under anticyclonic circulation.

THIRD WEEK

Further retrogression of the circulation features, and the attendent weather anomalies, took place from the second to the third week of the month (figs. 3C, 4C, 5C). The mid-continental trough sheared and joined the California trough as the latter intensified. The block in the Gulf of Alaska weakened as it moved westward. The east coast ridge also weakened.

The eastern third of the United States had continued hot weather (fig. 4C), with new maximum temperature records set in Schenectady, N. Y., on the 21st and 22d. Temperature anomalies were most extreme in the Northeast, where a departure of +10° F. was observed in Caribou, Maine, +9° F. in Concord, N. H., and +8° F. in Baltimore, Md. Precipitation was generally abundant in the eastern half of the Nation in broad southerly flow ahead of the mean trough (fig. 5C).

Tropical storm Esther entered the mainland over southeastern Louisiana (fig. 6), with winds of 50 m. p. h. and gusts up to 75 m. p. h. It was the third tropical storm this season to make landfall on the same narrow strip of coastline. Esther was responsible for torrential rains which fell in squalls northeast of its center. Rain in excess of 10 inches was not uncommon, and as much as 18 inches was recorded at Quarantine, La. Highest tides ranged from 2 feet above normal on the western Louisiana coast and near Pensacola, Fla., up to 6 feet above normal along the southeastern Louisiana and Mississippi coasts. Flooding from heavy rains occurred through southeastern Louisiana and near the Mississippi and Alabama coasts.

Heavy rains with totals up to 11 inches fell on Oklahoma and eastern Texas, resulting in local flooding as a cold front moved through the area. Cyclonic conditions are apparent in that region on the mean map (fig. 3C).

A small tropical depression formed south of Louisiana on the 16th and entered northwestern Florida, causing

heavy precipitation in parts of the Southeast. It is possible that this depression was the beginning of hurricane Frieda, which developed off Bermuda on September 20 (fig. 6 and Chart X). Esther and Frieda will be discussed in greater detail in the following sections.

Warm and dry weather still prevailed over a narrow strip along the Pacific coast (fig. 4C and 5C), partly due to a diminished sea-breeze circulation as cold inland temperatures predominated. The remainder of the Nation was unseasonably cool (fig. 4C) as polar anticyclones continued to traverse the Great Plains (Chart IX). Departures from normal of the average temperature were −11° F. in Montana, −9° F. in Minnesota, North Dakota, South Dakota, and Wyoming, and −8° F. in Nevada. Record minimum temperatures and killing frost were experienced at stations in Oregon, Washington, Montana, and Idaho. The record minimum temperature in Helena, Mont., contrasted with record maxima there in both the first and fourth weeks of the month.

As a cold airmass moved slowly from the northwest and an upper-level Low from the southwest, significant snowfalls were recorded in the Rocky Mountain region with Helena, Mont., observing a record-breaking September accumulation of 13.4 inches and a 24-hour total of 9 inches. Drifts over 3 feet deep were reported in Logan Pass in Glacier National Park.

FOURTH WEEK

A major circulation change took place from the third to the fourth week as troughs and ridges moved rapidly eastward (fig. 3D). The mean trough in the United States sheared once more, with the southern portion becoming established along the coast of Lower California and the remainder marching eastward across the country to join the low-latitude trough of hurricane Frieda.

A trough remained in the Gulf of Mexico, extending northeastward into Tennessee, and was associated with heavy precipitation along the Gulf coast. The rains extended northward parallel to the trough in the southerly flow to its east. At the surface a weak wave developed in the northwestern Gulf on the 23d and stagnated until the 26th, when it began to drift slowly eastward (Chart X). A small area of heavy precipitation south of Hatteras during the fourth week was associated with a wave cyclone that moved northeastward parallel to that portion of the coast on the 29th–30th. The only other notable precipitation was in northern California and southern Oregon, where record 24-hour falls occurred as a consequence of the onshore flow and cyclonic conditions discussed in section 2. The rest of the country was dry as a large High became established in the Southwest (fig. 3D), and a long fetch of northwesterly flow invaded the northern two-thirds of the Nation.

The sharp reversal in the temperature field (fig. 4D) is easily understood against the background of the circulation changes. Cold weather was the rule in the eastern half of the United States. Temperatures dropped sharply as two thrusts of cold air were injected into the East, with anomalies at Caribou, Maine, sliding from +10° F. for the third week to −8° F. Temperature departures from normal were as great as −11° F. at such diverse stations as Youngstown, Ohio, and Greenville, S. C. Record minima for the date, the month, and for so early in the season were set at many scattered stations throughout the East, Midwest, and South.

With clear skies and abundant sunshine in association with the High in the Southwest, the western half of the Nation experienced a heat wave of record-breaking proportions. Salt Lake City, Utah, broke maximum temperature records on the last 3 days of the month. New daily maxima were also set on those days and on the 27th at stations in Colorado, Montana, and Wyoming. The most extreme weekly temperature departures were +12° F. in Great Falls, Mont., and +11° F. in Salt Lake City.

Temperatures for the week were 5° F. below normal in a small pocket in the upper Sacramento Valley (fig. 4D). Early in the week, it was warm, but, from the 26th through the 30th, thick clouds blanketed the area and kept maximum temperatures suppressed an average of 16° F., while the minima remained near normal. On 3 days the percentage of possible sunshine ranged from 0 to 7 percent.

4. TROPICAL STORMS RELATED TO THE MONTHLY CIRCULATION

ATLANTIC STORMS

Of the four tropical storms which formed in the Atlantic and Gulf of Mexico during September two developed into hurricanes, compared to mean values of three storms and two hurricanes during the past 70 Septembers. Although four or more tropical cyclones have occurred slightly more than one-fourth of the time in September, since 1953 this frequency has been observed five times in succession. This can be explained in part perhaps by increased data.

Though conditions for tropical cyclogenesis were not the most ideal according to composite circulation types outlined by the author [1, 2] the circulation in September was more favorable than in the previous month. In August, westerly anomalous flow prevailed over a large part of the subtropical Atlantic, and, despite favorable sea-surface temperatures, only one storm formed. This storm developed in the Gulf of Mexico, which has been the preferred area this hurricane season. To date, five of the seven tropical storms (including two in September) have developed in the Gulf. 1936 was the only previous year on record in which five or more storms developed in the Gulf of Mexico. In that year a total of 17 tropical storms developed in the Atlantic region, so that even though 6 formed in the Gulf the concentration was not as great as this year. Conditions were favorable in the Gulf in September as easterly wave activity with concomitant cyclonic vorticity prevailed, and cooler than normal mid-tropospheric temperatures overlay warm sea-surface temperatures [8].

It is believed that the favorable climate for tropical storm formation includes warm sea-surface temperatures;

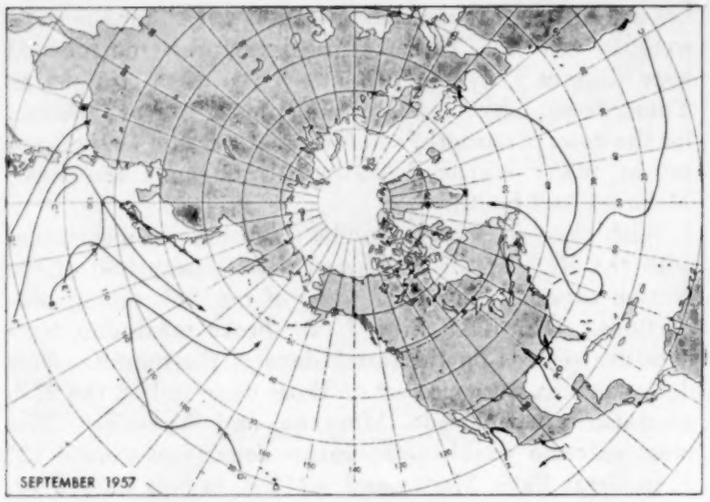

FIGURE 6.—Preliminary tropical storm tracks for September in both the Atlantic and Pacific Oceans. The track of Frieda (F) from the Gulf of Mexico to its "official" origin near Bermuda is hypothetical.

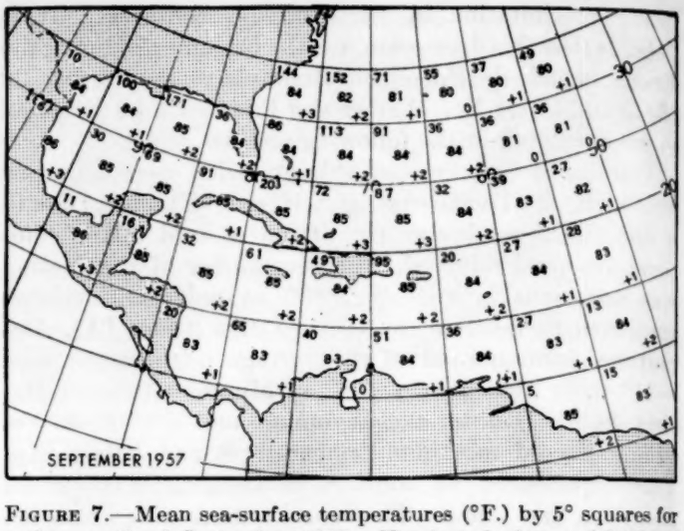

FIGURE 7.—Mean sea-surface temperatures (°F.) by 5° squares for the month of September 1957. Numbers in lower right hand corner of each box are the departure from normal in °F.; those in upper left give the number of ship observations (from twice-daily synoptic maps) on which the data are based. Water temperatures were especially warm throughout the area.

Palmén [11] set a criterion of 78°–81° F. Since June 1957 all ship observations of water temperatures plotted on twice-daily synoptic charts have been tabulated for the 5° squares delineated in figure 7 (and for the squares extending east to Africa) and computed by 10-day and monthly means. The mean temperatures for the month of September appear in the center of each square (fig. 7). A comparison with the long-period (1887–1936) averages given by Riehl [12] is in the lower right corner, and the number of observations is given in the upper left corner of each box.

It is apparent that throughout September the sea surface was warmer than both the critical temperature of 81° F. and the long-period average in the ocean area shown. Temperatures were extremely high from June to September in the Gulf of Mexico, reaching a peak in August; and they exceeded or equalled the threshold value throughout the hurricane breeding ground of the Atlantic during both July and August, in addition to September. Despite this, tropical storm activity was suppressed during July and August. It is probable that a diminution in sea-surface temperature below a critical value would inhibit the formation of tropical storms, but that temperatures equal to, or in excess of, the threshold value do not guarantee formation unless synoptic conditions are also favorable.

This September the peak speed of the westerlies (jet), computed geostrophically from the monthly mean 700-mb. chart (fig. 1), was farther south than normal throughout the Atlantic (fig. 8A). Although it is popularly believed that when the jet is north of normal, tropical storm activity is great, and when south of normal diminished, this generalization is perhaps secondary in importance to the wind distribution to the north of the normal breeding grounds. Note the belt of stronger than normal westerlies at mid-latitudes of the Atlantic, surmounting another one of easterly anomalous flow at lower latitudes (fig. 8B). This resulting increase in latitudinal wind shear encourages the fracture of extended troughs and the possible retrogression of their southern portions. Observation has shown the importance of a band of easterlies in the zone of formation [15], a condition realized this month as a continuous band of easterlies girdled lower latitudes from Africa to the western Pacific.

The behavior of the tropical storms (fig. 6) can be interpreted in terms of the monthly circulation (fig. 1). Both Debbie and Esther moved roughly parallel to the isopleths of 700-mb. height departure from normal. Namias [8] pointed out several cases of storm trajectories behaving in similar fashion. In addition, Esther moved northward just east of the mean trough for September, and Debbie moved northward just east of the mean trough for mid-August to mid-September (dashed trough in fig. 1). Such behavior has been noted in the case of Audrey by Klein [6], who lists many other *Monthly Weather Review* articles on the weather and circulation illustrating similar hurricane motion in relation to the mean circulation.

The recurvature of Carrie also paralleled a mean trough. This trough in the western Atlantic was not merely a reflection of the passage of the storm on 700-mb. heights in the region traversed, since removal of the days when Carrie was in that region from the 30-day mean does not completely eliminate the trough (not reproduced).

Carrie had an extremely long life, traveling approximately 6,000 miles in 24 days, and was classified as a hurricane for 20 days from the Cape Verde Islands to a point east of the Azores. The maintenance of the hurricane circulation for so long a period is associated with its oceanic trajectory and points up many problems involv-

ing atmospheric vortices. Carrie reached its greatest intensity about 1,000 miles east of Puerto Rico in the area where the monthly mean 700-mb. vorticity (computed from fig. 1, but not reproduced) was much more cyclonic than normal. (An indication of this vorticity is the −10 center in the height anomaly field of fig. 1.) At that time its winds were 160 m. p. h.; though hurricane-force winds did not affect any land areas, Carrie presented a hazard to North Atlantic shipping during its long existence. On September 21, Carrie was associated with the sinking of the German sailing vessel *Pamir* with a loss of 80 lives.

Hurricane Frieda reached its greatest intensity in an area of cyclonic vorticity near the apex of the mean trough traversed by Carrie. Its motion subsequent to its intensification does not fit the 30-day mean pattern as well as it does the 5-day patterns (section 5). However, features of the monthly mean that do appear to have influenced its path, and also that of Carrie, are the prevailing ridge along the east coast of the United States (fig. 1) and, particularly, the stronger than normal westerlies over the Northeast (fig. 8) which deterred tropical storm penetration into that area [9, 1].

EASTERN PACIFIC

Of interest this month were the three tropical storms which formed in the eastern Pacific near Mexico (fig. 6), one of which was a hurricane. They formed in an area of predominantly below normal heights on the mean 700-mb. chart, and two of them moved toward the north in the southerly flow ahead of the mean trough. The third storm had a forward speed of about 10 m. p. h. A final bulletin issued by San Francisco on the 27th stated that it was impossible to follow that storm beyond 15° N., 104° W., due to lack of reports in the area. Subsequently a circulation was detected at 0000 GMT on October 1 at 19° N., 119° W. (not shown on fig. 6). During October the storm developed into a hurricane that recurved northeastward across Lower California into Mexico. If storm number 3 (fig. 6), which could not be tracked beyond the position given above, had continued to drift west-northwestward with a speed of 11 m. p. h., it would have arrived at the point where the circulation was detected on October 1. It is therefore conceivable that these two storms were the same one.

WESTERN PACIFIC

When this month began, Typhoon Bess (B′ on fig. 6) had already formed. Five other typhoons were observed in the western Pacific during September, although only four typhoons formed. This paradox is the result of semantics, since tropical storms with winds in excess of 75 m. p. h. are called hurricanes east of 180° and typhoons west of 180°, and a hurricane observed first on September 4 at 163° W. was renamed typhoon Della (D′) after it crossed the 180th meridian on the 7th.

Four of the six typhoons observed this month recurved in the southerly flow between the Asiatic trough and the subtropical High. These four storms recurved sharply into the Aleutian Low south of a strong blocking High over Kamchatka. This Low was regenerated from time to time and acted as a sink for the cyclonic vorticity of these typhoons and a source for the cyclone tracks leaving that area (Chart X) and traveling across the top of the blocking ridge in the eastern Pacific.

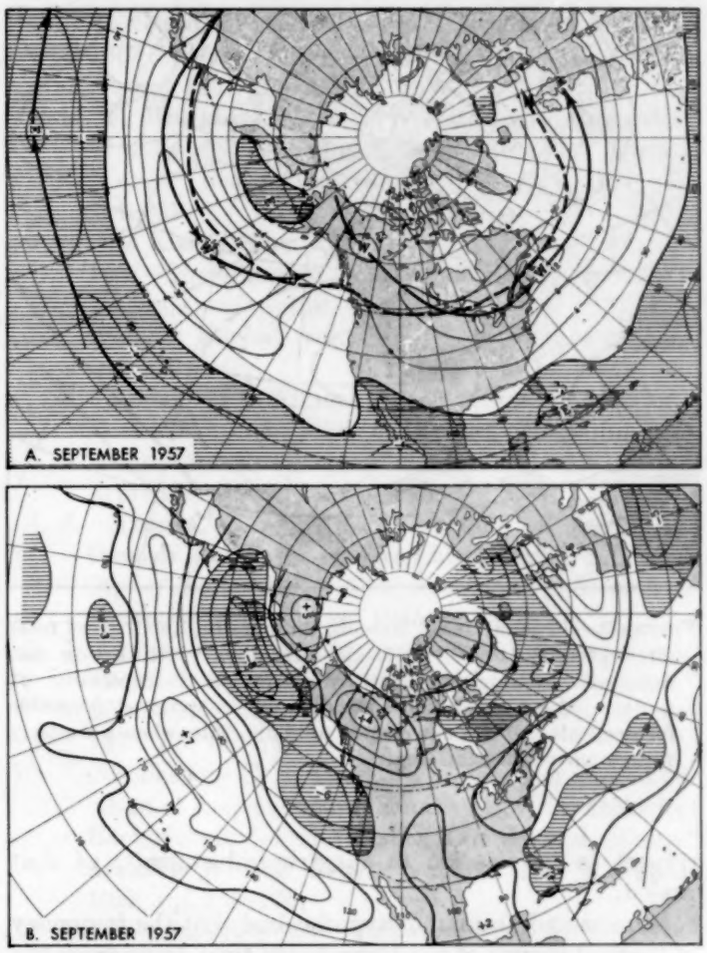

FIGURE 8.—Mean 700-mb. isotachs of the zonal wind speed component (A) and its departure from normal (B) (both in meters per second). Solid arrows in (A) indicate positions of the mean axes of 700-mb. zonal wind maxima, and dashed arrows give their normal September position. Centers of easterly and westerly flow are labeled E and W, respectively. Easterly flow is considered negative and shaded. The hatched shading in (B) delineates areas where the departure from the normal zonal flow equalled or exceeded 2 meters per second from the east. Note the effect of blocking in middle and high latitudes, producing anomalous flow components from the east.

5. TROPICAL STORMS RELATED TO THE 5-DAY MEAN CIRCULATIONS

The relation of the tropical storms of the Atlantic to the 5-day mean circulations deserves special attention. Features that were not too clear in the previous section will be brought into sharper focus. Each 5-day mean map (fig. 3) will be discussed in chronological order with

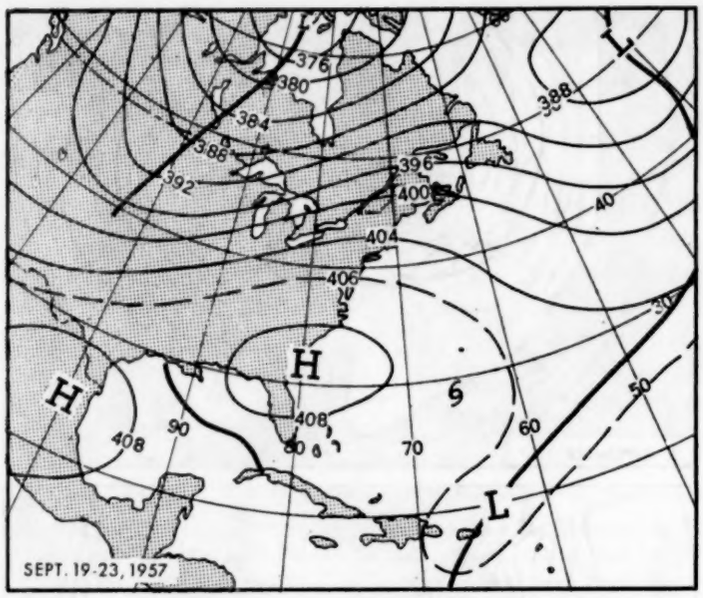

FIGURE 9.—Five-day mean 200-mb. contours (in hundreds of feet) for September 19–23, 1957, the period in which Frieda was detected. Although the position of Frieda on September 21 (designated by the tropical storm symbol) appeared favorable for deepening, it did not deepen until the 25th when a westerly trough moved into the area.

respect to its relation to the tropical storm(s) of that period.

Namias and Dunn [10] hypothesized that the frequency of tropical storms of the Cape Verde type depends on the degree of development of the Azores ridge to the north. They stated that when the ridge of the Azores upper-level anticyclone is thrust strongly northeastward into Europe, cyclonic vorticity is injected into a trough off the African coast. They cited the antecedent conditions associated with hurricane Connie in August 1955 as an example of this type of development (their fig. 4). The author [16] has noted that conditions favorable for tropical storm generation in the Cape Verde area are such that large positive height anomalies appear near western Europe—possibly a manifestation of a stronger than normal Azores High extending far northward. The 700-mb. conditions prior to the formation of Carrie on September 2 (not reproduced) were very reminiscent of those preceding Connie, and provide further evidence for the hypothesis expounded by Namias and Dunn [10].

On the morning of September 7, a weak cyclonic circulation, Debbie, developed in the central Gulf of Mexico as the result of juxtaposition of an easterly wave and a stagnant trough aloft. Debbie intensified very little as it moved northeastward in the southerly flow ahead of the trough. Conditions were not favorable for intense deepening as southwesterlies were above the storm in both the middle and upper troposphere [13]. On September 8 (fig. 3a) Debbie went inland at Fort Walton, Fla., with winds of 40 m.p.h. (associated weather described in section 3).

Subsequent to its development on September 2, Carrie moved eastward south of a zonally oriented ridge (fig. 3A). The storm continued its westward march until the 10th when it encountered a low-latitude trough (fig. 3a) that had moved about 5° to the east from its former position (fig. 3A) and influenced Carrie's abortive recurvature. This low-latitude trough joined with a high-latitude trough that deepened as the upstream wave train amplified. Carrie drifted north in the mean trough at about 5–10 m. p. h. during the period September 10–14 (fig. 3B).

The strong ridge along the east coast of North America (fig. 3B) sheared during the next period (fig. 3b), and the westerlies over eastern Canada increased greatly in speed. As a result, the short wavelength between the mid-continental trough and the western Atlantic trough (fig. 3B) could no longer be supported, and the upper portion of the Atlantic trough sheared and amalgamated with a retrogressive trough in the eastern Atlantic. In association with these fundamental changes in the circulation, a ridge crested across the Atlantic to the north of Carrie, impeding its northward motion. Carrie turned to the northwest on the 15th and on the 17th recurved sharply as it came under the influence of the westerlies north of the ridge.

A mid-tropospheric cyclonic circulation over Nicaragua on September 12 drifted northwestward to the southwestern Gulf of Mexico on the 15th. Tropical storm Esther formed under this circulation at the base of the mid-continental trough. Relatively few of the Gulf storms deepen into hurricanes (less than one-third of the September storms), and Esther was part of the majority. As it moved northward just to the east of the trough, the base of the westerlies was apparently too low for major deepening [14]. Esther moved inland on the southeastern Louisiana coast about daybreak of the 18th and continued northward up the Mississippi Valley, losing its identity on the 19th (fig. 3C).

On the 16th a weak tropical depression was located in the northeastern Gulf of Mexico, and it moved inland that morning (fig. 3b). This Low moved northeastward and eastward to the North Carolina-South Carolina border early on the morning of the 18th. At that time it was a frontal wave which progressed eastward by a method of discontinuous cyclogenesis. It is thought that this wave cyclone eventually deepened into hurricane Frieda.

Dunn [3] has indicated that trailing, stationary, or fractured portions of old polar troughs may provide the initial concentration of cyclonic vorticity necessary for hurricane formation, a common occurrence in the area between the Bahamas and Bermuda [16]. It was mentioned in section 4 that Frieda formed at the apex of the monthly trough associated with Carrie; but these two storms can be even more closely linked. As Carrie moved rapidly eastward (Sept. 17 to 25) it left a trough behind. The extratropical Low over the South Atlantic States deepened as it approached this concentration of cyclonic vorticity near Bermuda, and the "official" preliminary track places the origin of Frieda in that

vicinity (fig. 3c). It continued to move southward, steered by the large-scale flow which appears on the 5-day mean (also paralleling the isopleths of height anomaly) (fig. 3c). Such a path, while uncommon, is not unprecedented; e. g., the famous "Yankee" hurricane of 1935 and a tropical storm in October 1938.

As Frieda continued to move southward and then loop northward (fig. 3, C and c), it proved to be an exception to the rule [13] that a northerly current at 200 mb. is favorable to deepening (fig. 9). This exception was expecially noteworthy in view of the fact that the anticyclone above Frieda was part of a ridge of the long-wave pattern in the westerlies during a period of considerable amplitude.

During the period September 21–25 (fig. 3c) large-scale retrogression ceased and eastward motion again became established. This eastward motion continued at an accelerated pace, and a deepened trough off the east coast of North America swept Frieda rapidly northward. It was not until this trough at both 700 mb. and 200 mb. came over the surface cyclone that the storm deepened to hurricane intensity (fig. 3D). It appears as if the intensification of Frieda cannot be divorced from the baroclinic conditions that accompany the transformation of tropical cyclones into extratropical ones. Trough intensification not only affects the motions of these storms but also provides a mechanism for extratropical development.

Meanwhile (fig. 3c) Carrie streaked eastward under westerly mean 700-mb. flow. On the 21st the *Pamir* sank in the vicinity of the storm, and on the 25th Carrie passed over Ireland as strong gales lashed the coast. It helped to deepen the Low over northern Europe on the last map of this series (fig. 3D).

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Weather Notes (continued from p. 302)

The 500-mb. Low on the California-Mexico border at 0300 GMT, April 22, moved sharply northeastward and 24 hours later was centered in west-central Colorado (see fig. 1 for the storm track at the 500-mb. level). Light precipitation was reported at scattered points in Utah and other portions of western United States on the 21st. As the cold Low aloft moved across the area on the 22d precipitation increased markedly, with much of Utah receiving moderate to heavy rain or snow. Precipitation was widespread over the State until 1500 GMT, April 23, when the 500-mb. Low was located over southeastern Wyoming.

PRECIPITATION

An isohyetal map for the Utah storm of April 22–23, 1957, is shown in figure 2. Precipitation was heaviest over north-central Utah, although most of the State received substantial amounts of moisture. Some of the heavier totals reported during the 2-day period were: Tooele 3.20 inches; Bauer 3.13; Beaver Canyon Power House 3.06; University of Utah at Salt Lake City 2.96; City Creek Water Plant (near Salt Lake City) 2.89, and Lower American Fork 2.69. Park Valley, in northwestern Utah, was the only station in Utah that did not report at least a trace during the storm.

Some of the precipitation was in the form of snow over much of the area. Beaver Canyon Power House, Silver Lake Brighton, and Timpanogos Cave, all mountain stations, received 29, 20.5, and 18 inches respectively; Cedar Point had 12 inches, Utah Lake Lehi 8 inches, and Tropic 7 inches. Four inches of wet snow fell at the Salt Lake City Airport, but only a trace was reported at Bountiful, a few miles to the northeast and at a higher elevation. In some sections, the heavy snow broke down power and telephone lines and numerous tree branches. The heavy rain and runoff from melting snow caused minor local flooding. Some losses to livestock and damage to fruit trees were also reported.

Several precipitation records were broken during the storm and these are tabulated in tables 1 and 2. Only stations with 10 or more years of record are included.

Probably the most outstanding record established during the storm was at the University of Utah, Salt Lake City, where 2.95 inches of precipitation fell in a 1-day period. This is the largest 24-hour amount ever recorded in the Salt Lake area.

Other all-time 24-hour precipitation records (for any month) established were: 2.41 inches at the Salt Lake Airport and 2.38 inches at Lower American Fork Power House.—*Merle J. Brown, State Climatologist, U. S. Weather Bureau, Salt Lake City, Utah.*

TABLE 1.—*April precipitation records for Utah stations for the 24-hour period ending at observation time each day. The new records were established during the storm of April 22–23, 1957*

Station	New record for April (in.)	Previous April record and date (in.)	Years of record
Alpine	1.77	1.60 (10/1905)	59
Beaver Canyon Power House	1.82	1.35 (28/1953)	18
Brigham City	1.68	1.30 (5/1929)	50
City Creek Water Plant	2.62	1.80 (6/1919)	40
Corinne	1.24	1.20 (10/1943)	85
Cottonwood Weir*	1.86	1.64 (16/1944)	40
Echo Dam	1.25	.67 (9/1947)	18
Farmington (Miller Floral)	2.37	1.85 (9/1953)	63
Fillmore	2.21	1.66 (1/1906)	66
Garland	.99	.98 (20/1947)	28
Grantsville*	1.12	1.08 (2/1913)	43
Lower American Fork Power House	**2.38	1.39 (29/1951)	44
Logan, Utah, State Agricultural College*	1.73	1.43 (20/1944)	66
Mountain Dell Dam	2.11	1.04 (5/1938)	38
Ogden Pioneer Power House	1.94	1.80 (28/1932)	88
Ogden Sugar Factory	1.55	1.50 (27/1932)	33
Richmond	1.54	1.37 (14/1921)	45
Riverdale Power House	2.18	1.80 (28/1932)	44
Terminal	1.78	1.10 (16/1941)	18
Tooele	2.10	1.56 (8/1900)	61
University of Utah	**2.95	1.43 (15/1952)	18
Utah Lake Lehi	1.25	1.00 (18/1909)	52
Woodruff	1.43	.98 (2/1940)	61

*All precipitation amounts in this table are for the 24-hour period ending at observation time. See table 2 for record April precipitation amounts for 24-hour periods beginning on any hour of the day.
**All-time record for the station for any month.

TABLE 2.—*New precipitation records for Utah for 3, 6, 12, and 24-hour periods for the month of April. These data were taken from recording rain gage charts of April 22–23, 1957, and the various periods begin on any hour of the day*

Station	Duration (hours)				Years of record
	3	6	12	24	
	(in.)	(in.)	(in.)	(in.)	
Cottonwood Weir				2.52	14
Farmington Warehouse				2.38	15
Grantsville	0.55		0.90	1.10	15
Logan, Utah, State Agricultural College		1.08	1.83	2.10	16
Salt Lake City (downtown)			*1.75	2.47	65
Salt Lake City Airport	.60	.80	1.79	**2.41	22

*Estimated.
**All-time record for the station for any month.

WORLD RECORD LOW TEMPERATURE

SOUTH POLE, SEPTEMBER 18, 1957

E. J. Flowers, Chief Meteorologist at the Amundsen-Scott IGY Station (South Pole), has reported that a new world record low air temperature, −102.1° F., was observed at screen level (2 m.) at 2137 GMT on September 18, 1957. (See p. 207 of June 1957 *Monthly Weather Review* for his report of the previous world record of −100.4° F. which occurred on May 11, 1957.) The wind and temperature report follows:

2137 GMT Sept. 18, 1957, Amundsen-Scott IGY Station

Wind		Temperature (°F)			
Direction (meridian)	Speed (kt)	Surface	Air		
			2 m.	5 m.	10 m.
110 E	4	−103.3	−102.1	−101.0	−79.5

An earlier dispatch reported the new record as occurring on September 17, but two subsequent messages from the South Pole station reported the occurrence on September 18. It is expected that a more detailed note by Mr. Flowers concerning this new record and the attendant weather conditions will be published in a future issue of the *Review*.—*Ed.*

New Storm Warning Signals

BEGINNING JANUARY 1, 1958, the U. S. Weather Bureau will put into use a new simplified system of flags and lights for giving warning of storms along the seacoasts and Great Lakes. Under the new system only four separate flag or light signals will be used instead of the seven now employed.

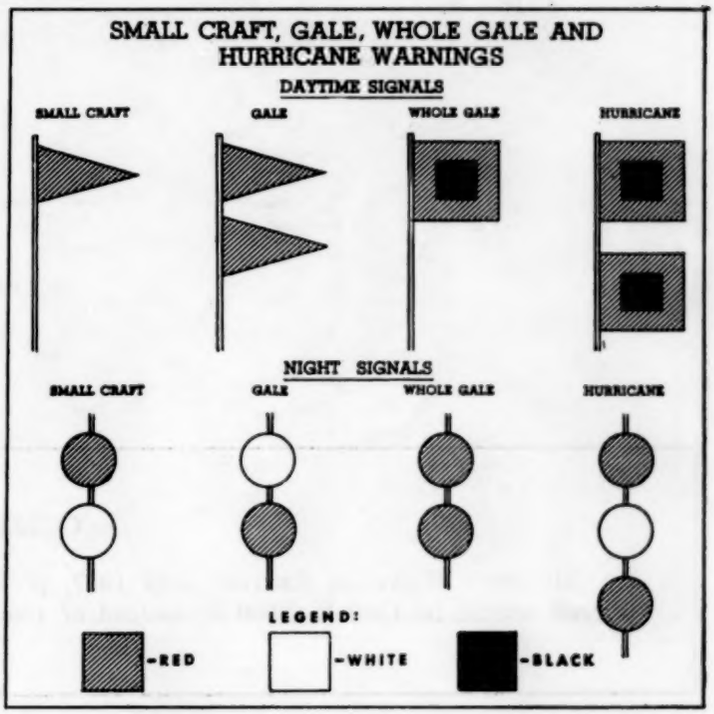
The explanation of the new signals, shown in the diagram below is as follows:

SMALL CRAFT WARNING: One red pennant displayed by day and one red light above one white light at night to indicate that winds up to 38 m. p. h. (33 kt.) and/or sea conditions dangerous to small craft operations are forecast for the area.

GALE WARNING: Two red pennants displayed by day and one white light above one red light by night to indicate that winds ranging from 39 to 54 m. p. h. (34 to 48 kt.) are forecast for the area.

WHOLE GALE WARNING: A single square red flag with a black center displayed by day, and two red lights at night to indicate that winds ranging from 55 to 73 m. p. h. (48 to 63 kt.) are forecast for the area.

HURRICANE WARNING: Two square red flags with black centers displayed by day and one white light between two red lights at night to indicate that winds 74 m. p. h. (64 kt.) and above are forecast for the area.

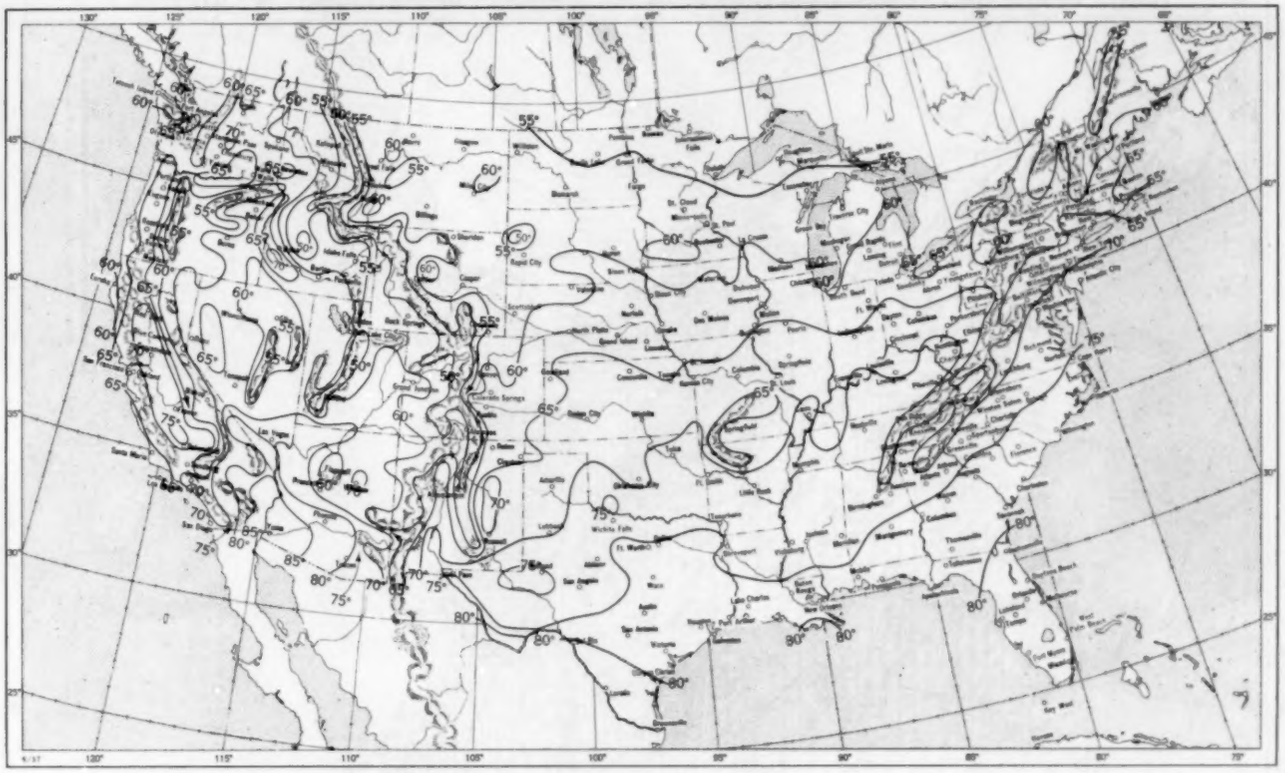


CORRECTION

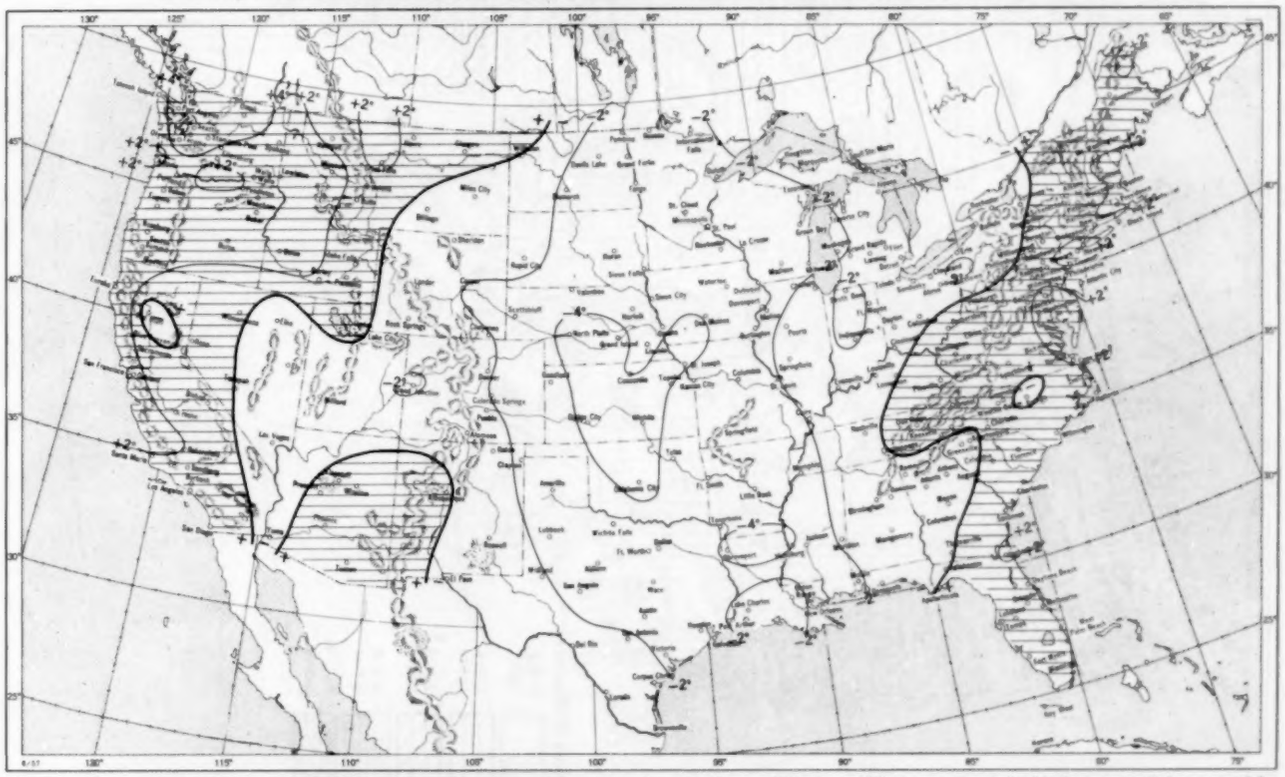
MONTHLY WEATHER REVIEW, July 1957, p. 248, fig. 4: Time of eye report from reconnaissance aircraft should be 1500 E (2000 Z) instead of 1500 Z.

U. S. GOVERNMENT PRINTING OFFICE: 1957

Chart I. A. Average Temperature (°F.) at Surface, September 1957.



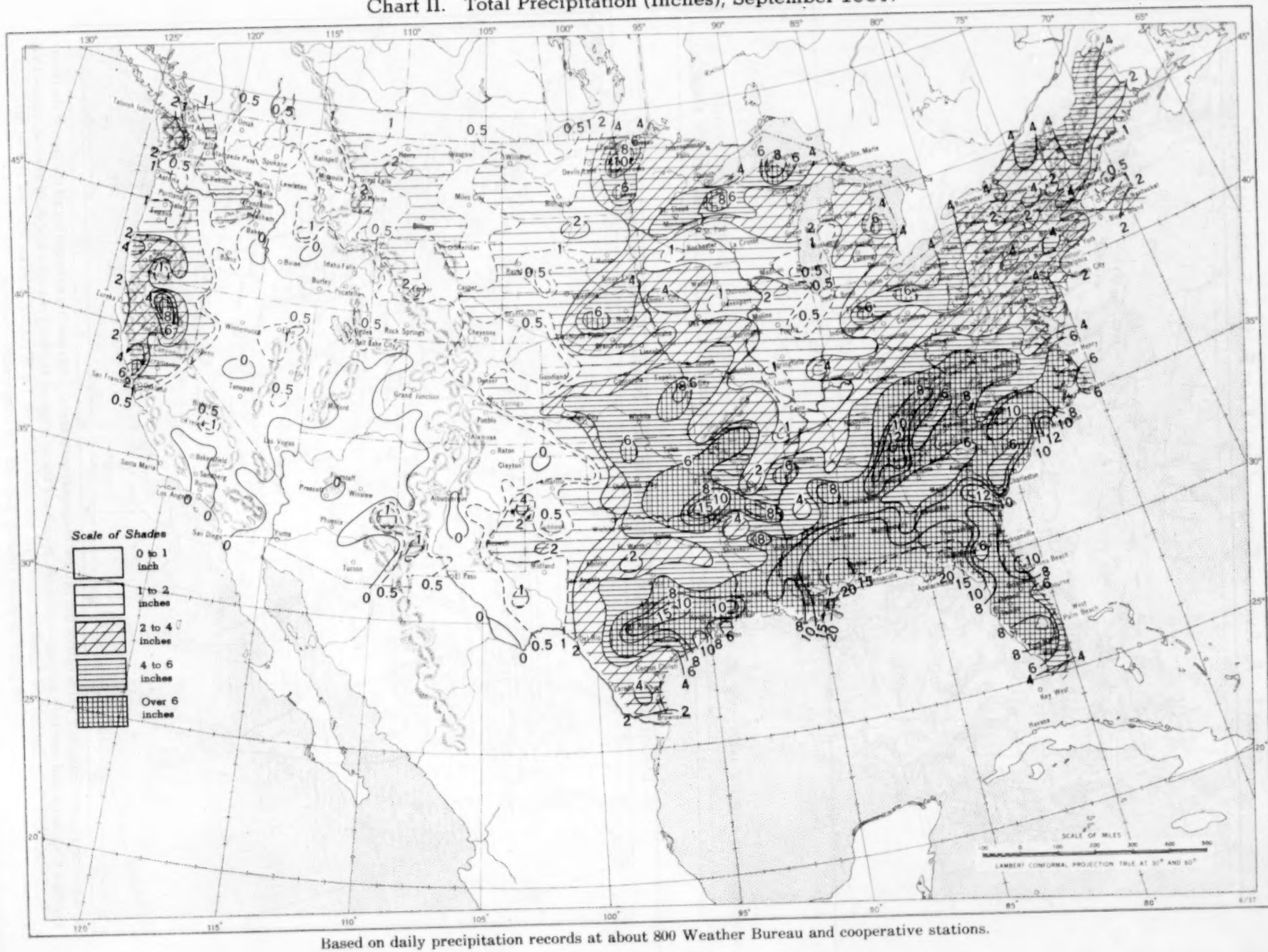
B. Departure of Average Temperature from Normal (°F.), September 1957.



A. Based on reports from over 900 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.

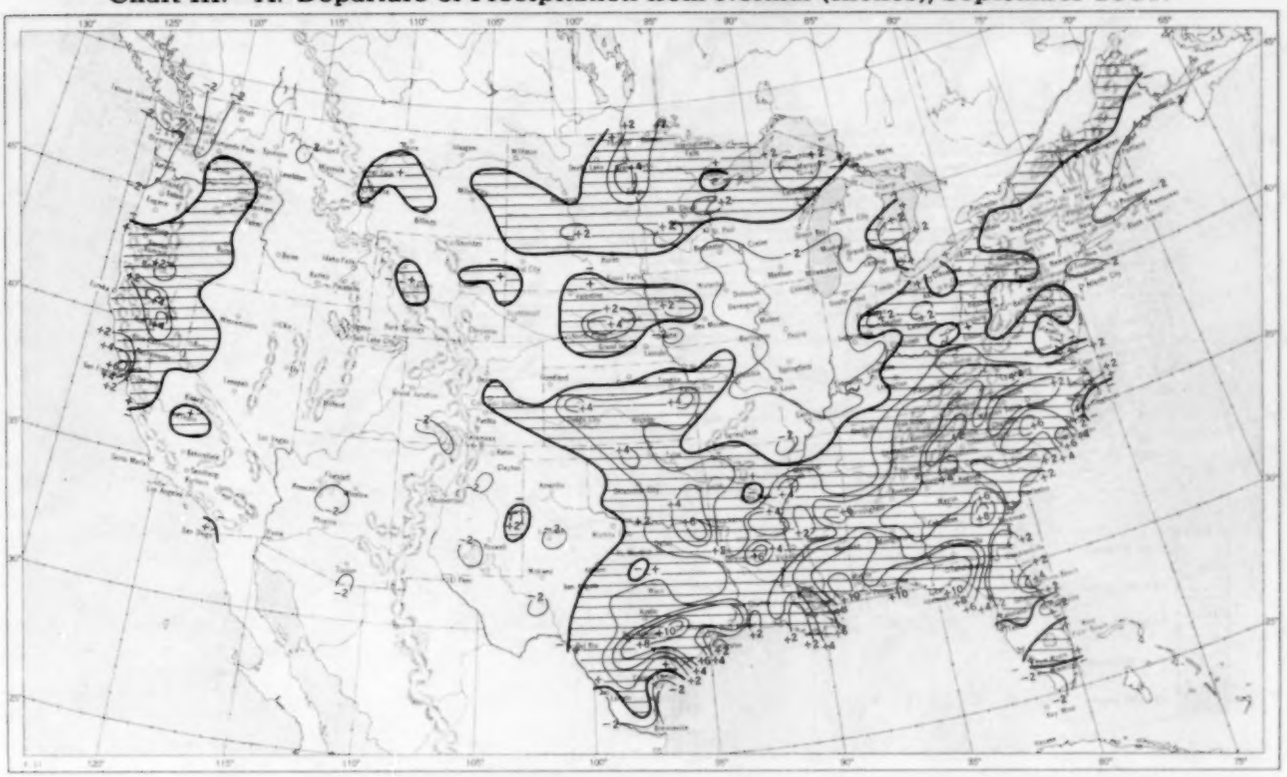
B. Departures from normal are based on the 30-yr. normals (1921-50) for Weather Bureau stations and on means of 25 years or more (mostly 1931-55) for cooperative stations.

Chart II. Total Precipitation (Inches), September 1957.

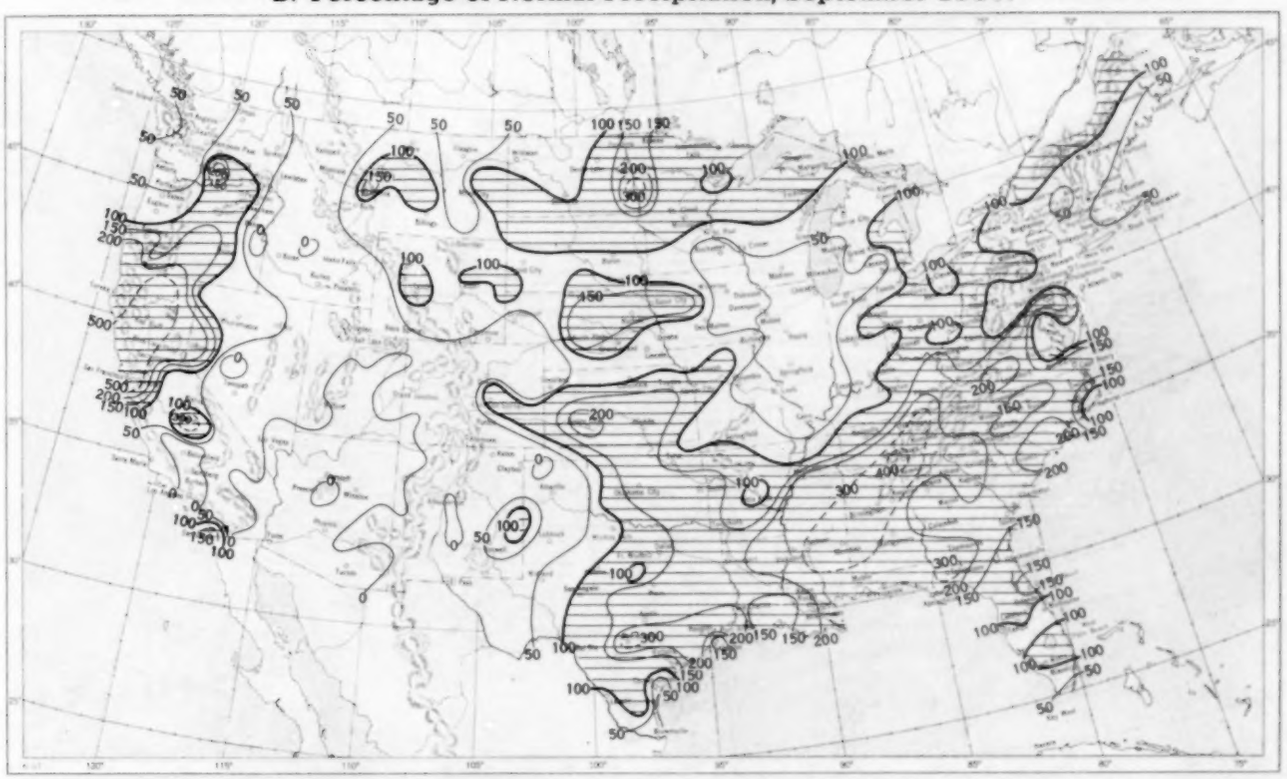

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at about 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), September 1957.

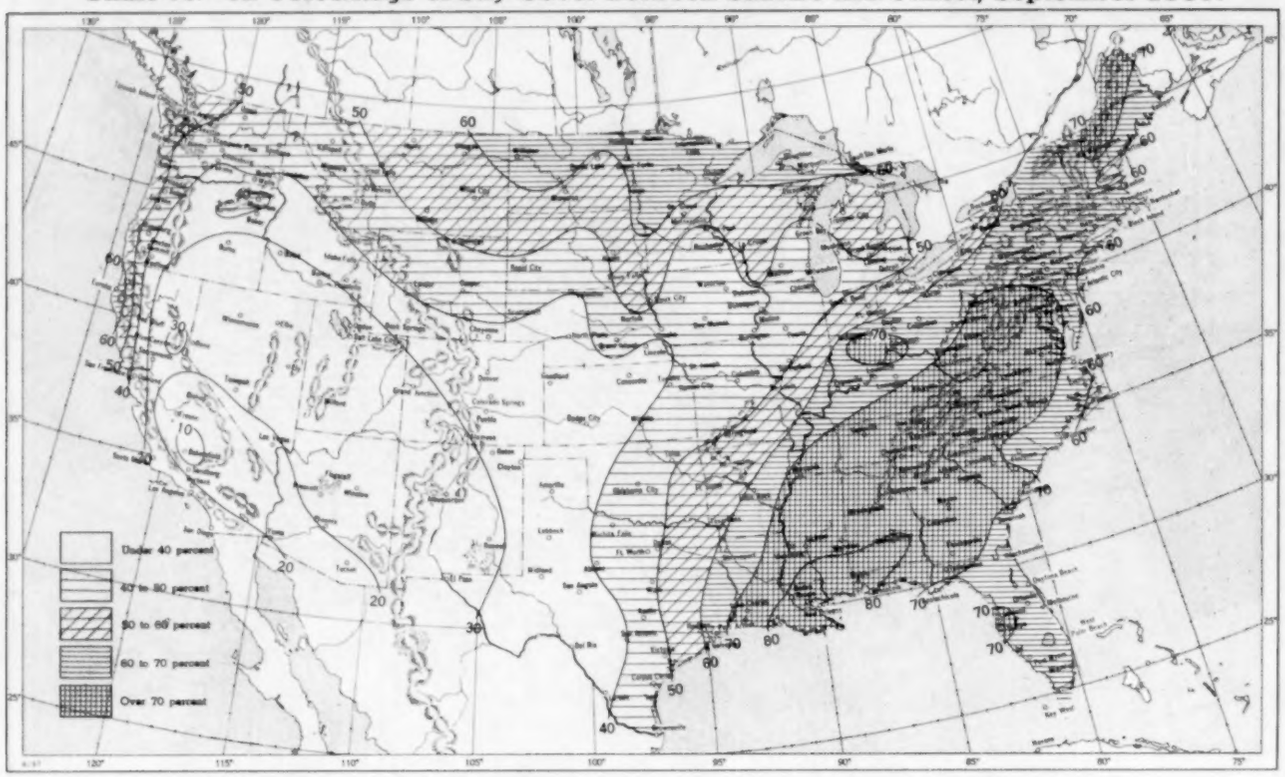


B. Percentage of Normal Precipitation, September 1957.

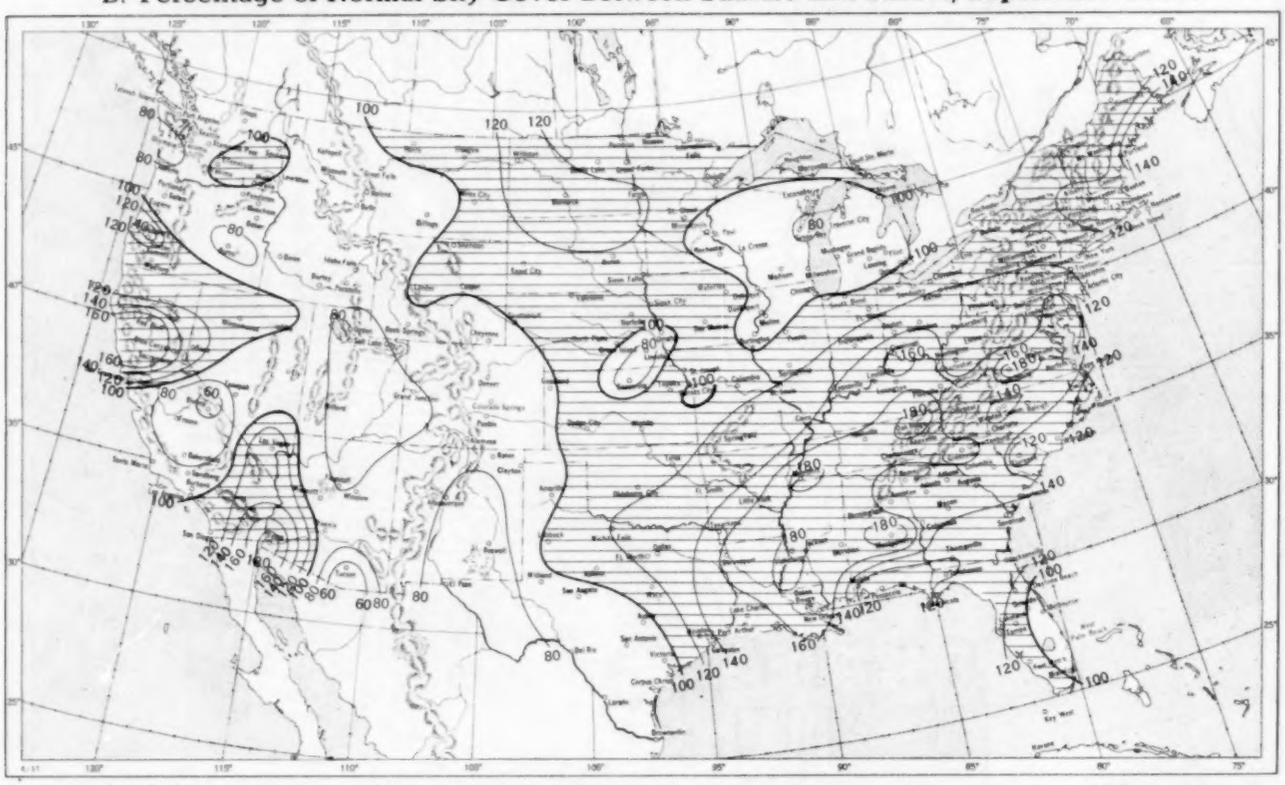


Normal monthly precipitation amounts are computed from the records for 1921-50 for Weather Bureau stations and from records of 25 years or more (mostly 1931-55) for cooperative stations.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, September 1957.

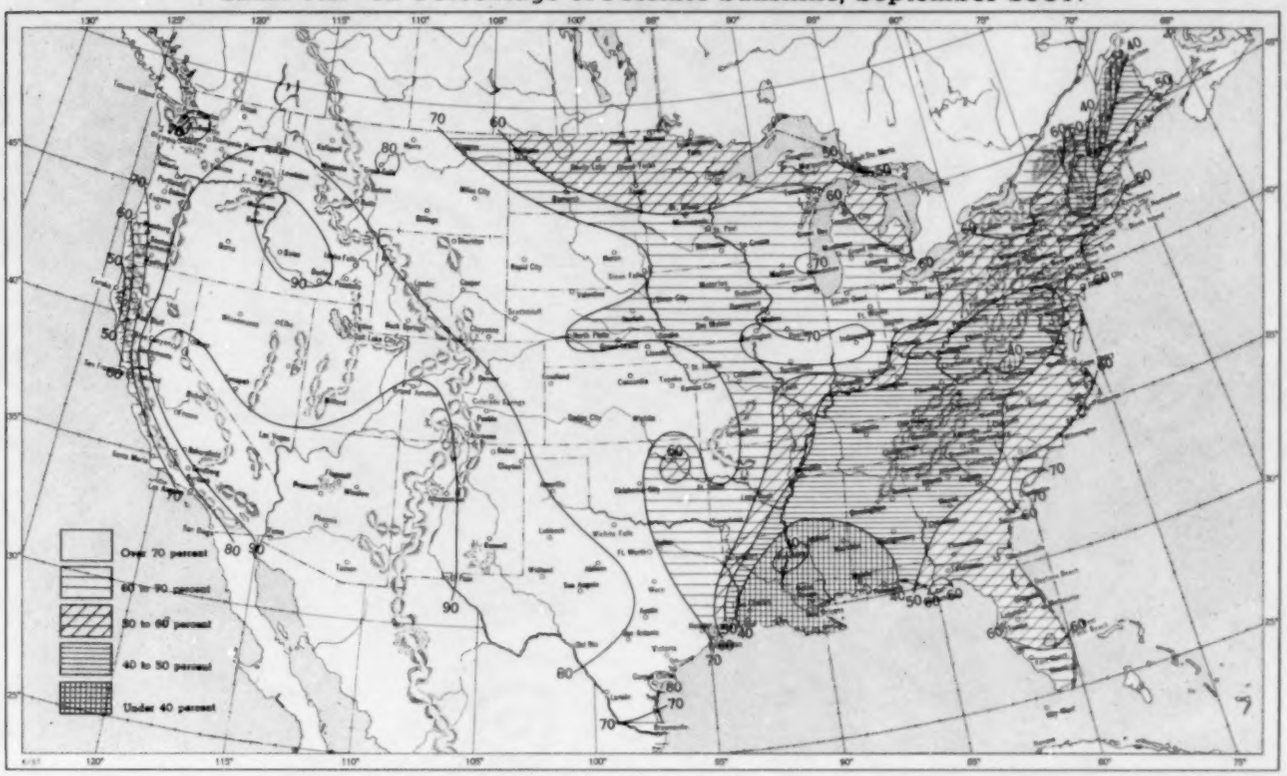


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, September 1957.

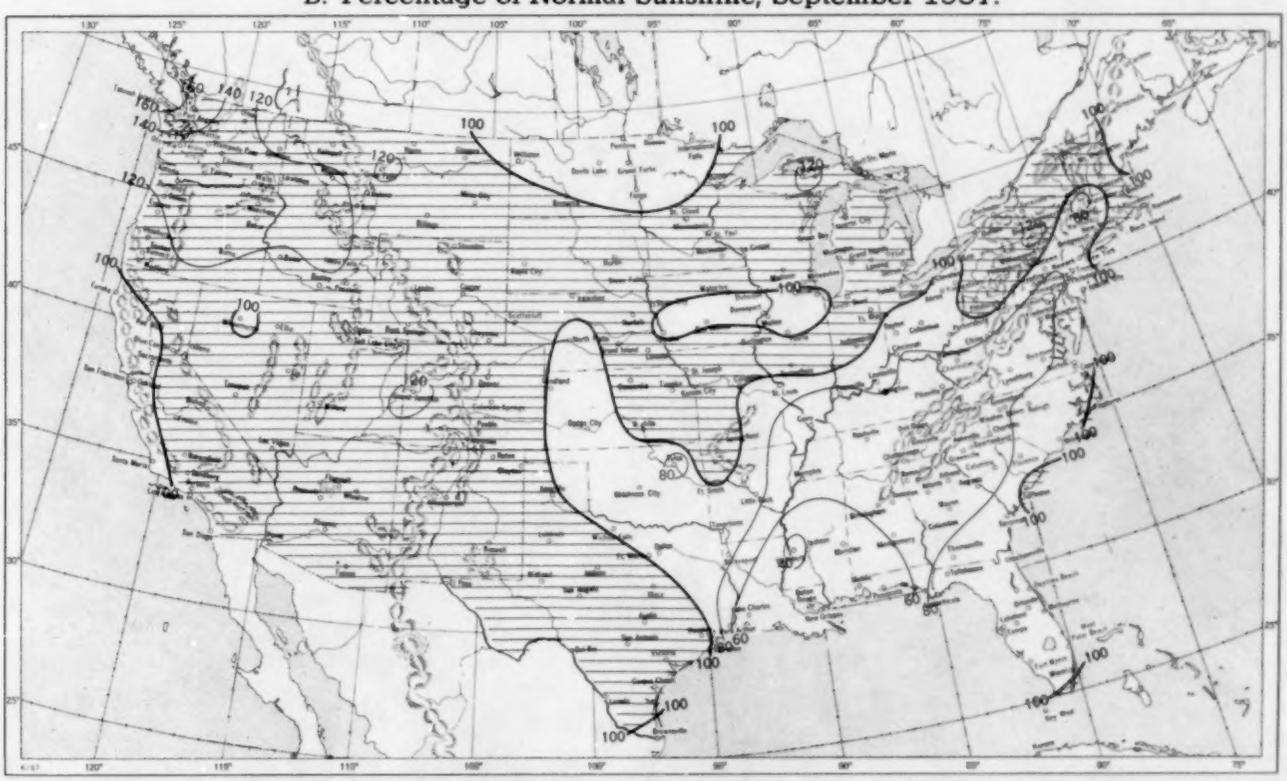


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, September 1957.



B. Percentage of Normal Sunshine, September 1957.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, September 1957. Inset: Percentage of Mean Daily Solar Radiation, September 1957. (Mean based on period 1951-55.)

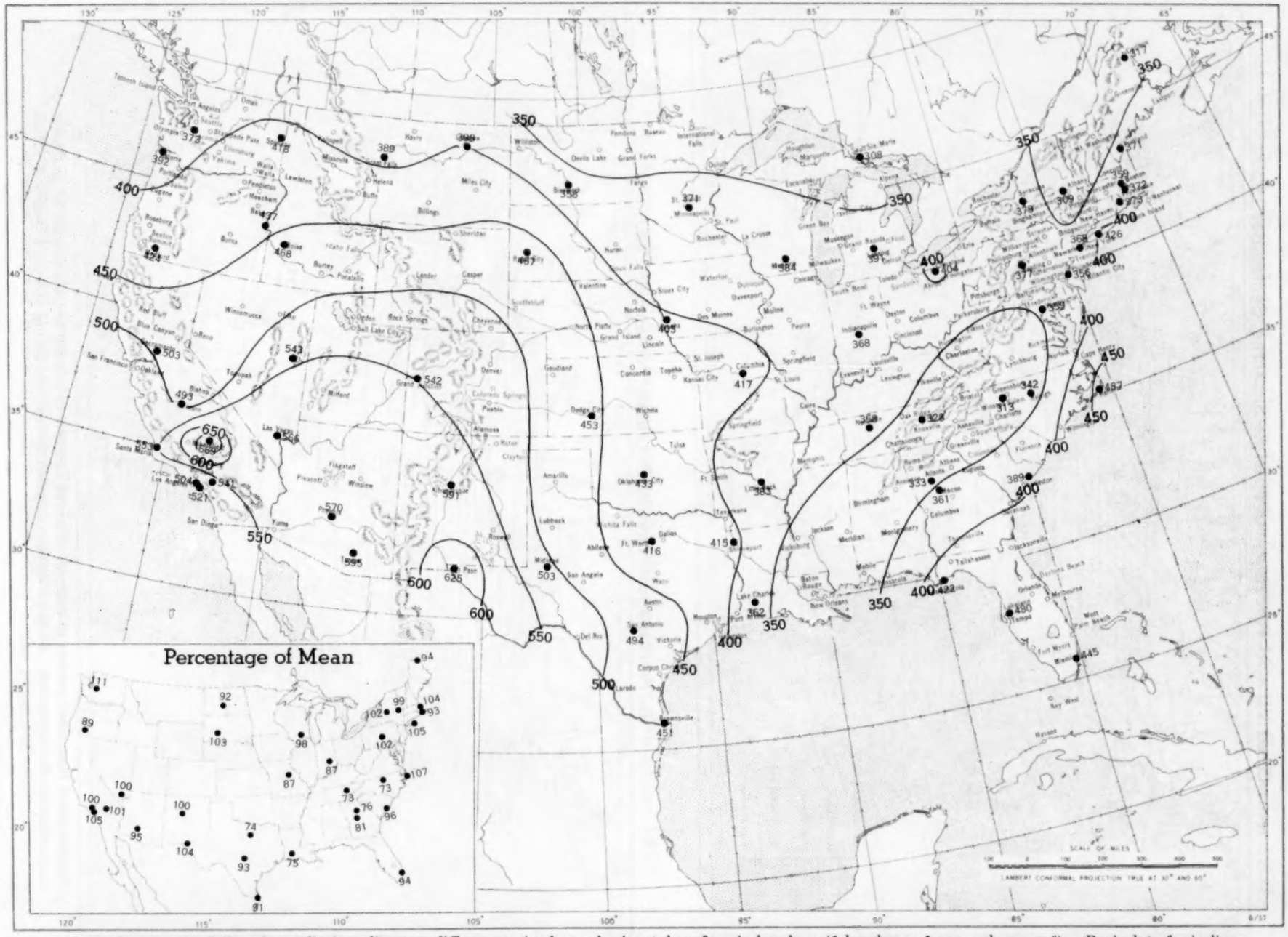
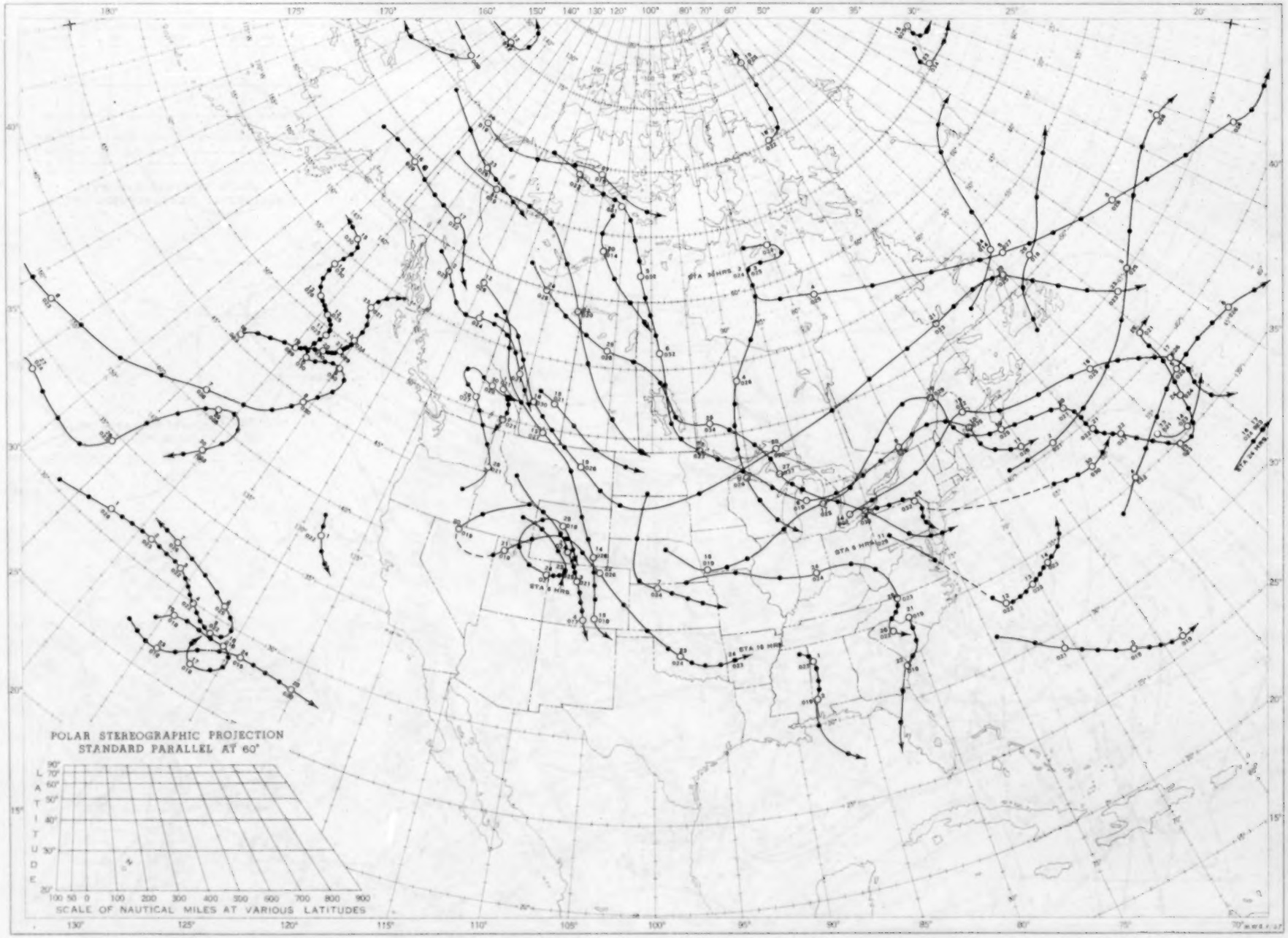


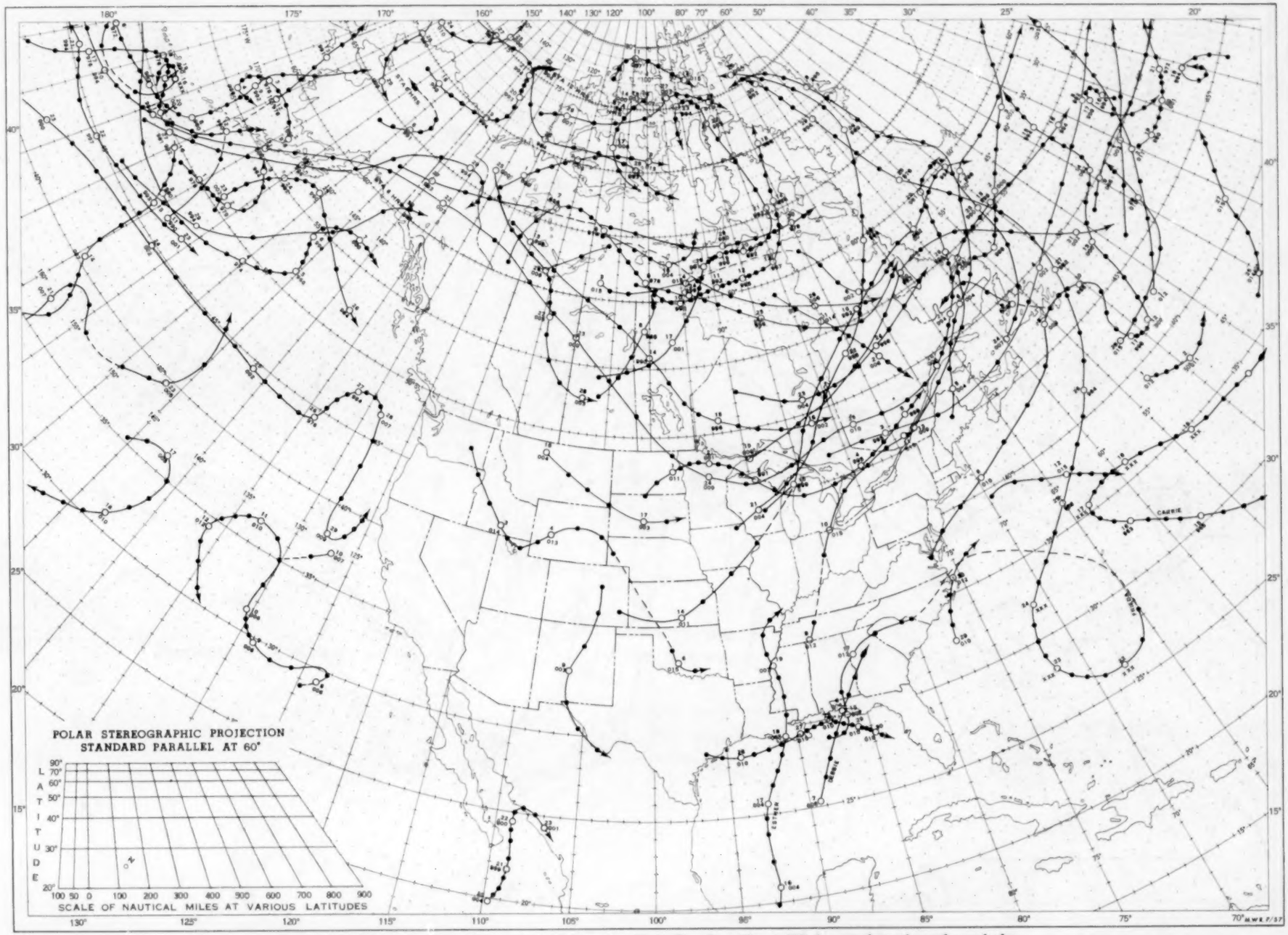
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. The inset shows the percentage of the mean based on the period 1951-55.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, September 1957.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
LATITUDE
90° 70° 60° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900
SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES

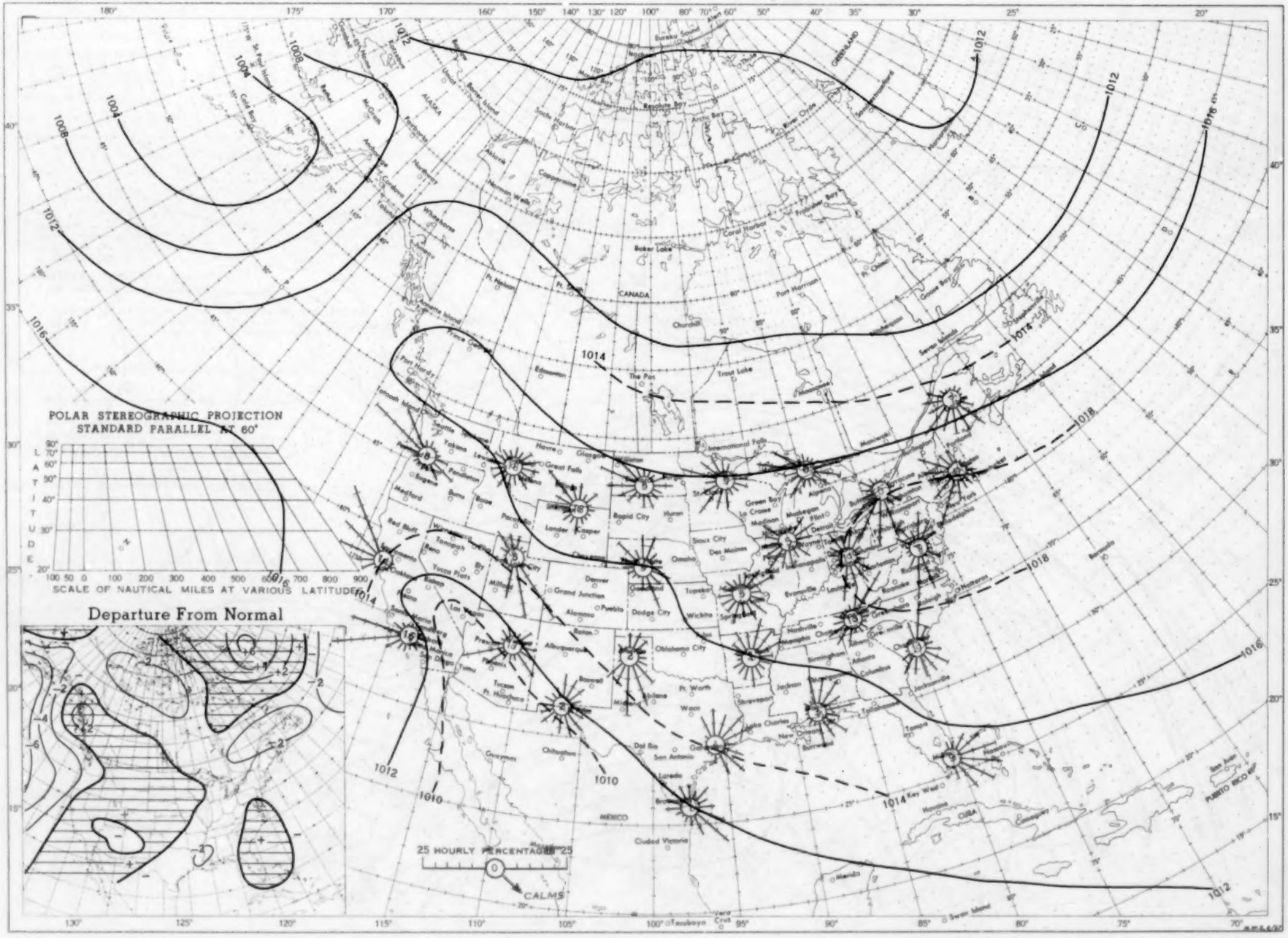
Circle indicates position of center at 7:00 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, September 1957.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
LATITUDE
90° 70° 60° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900
SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES
CARRIE
M.W.R. 9/57

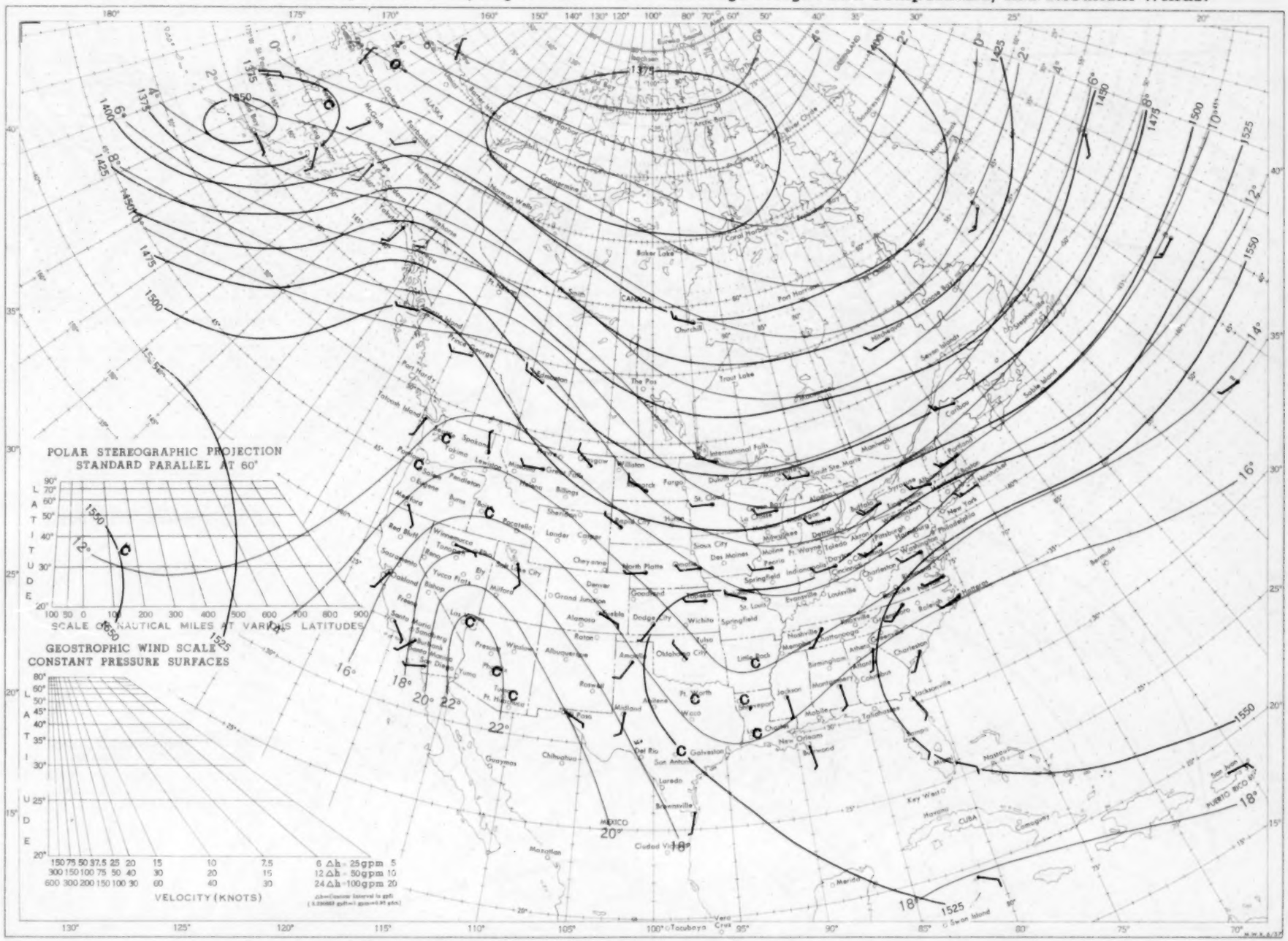
Circle indicates position of center at 7:00 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, September 1957. Inset: Departure of Average Pressure (mb.) from Normal, September 1957.



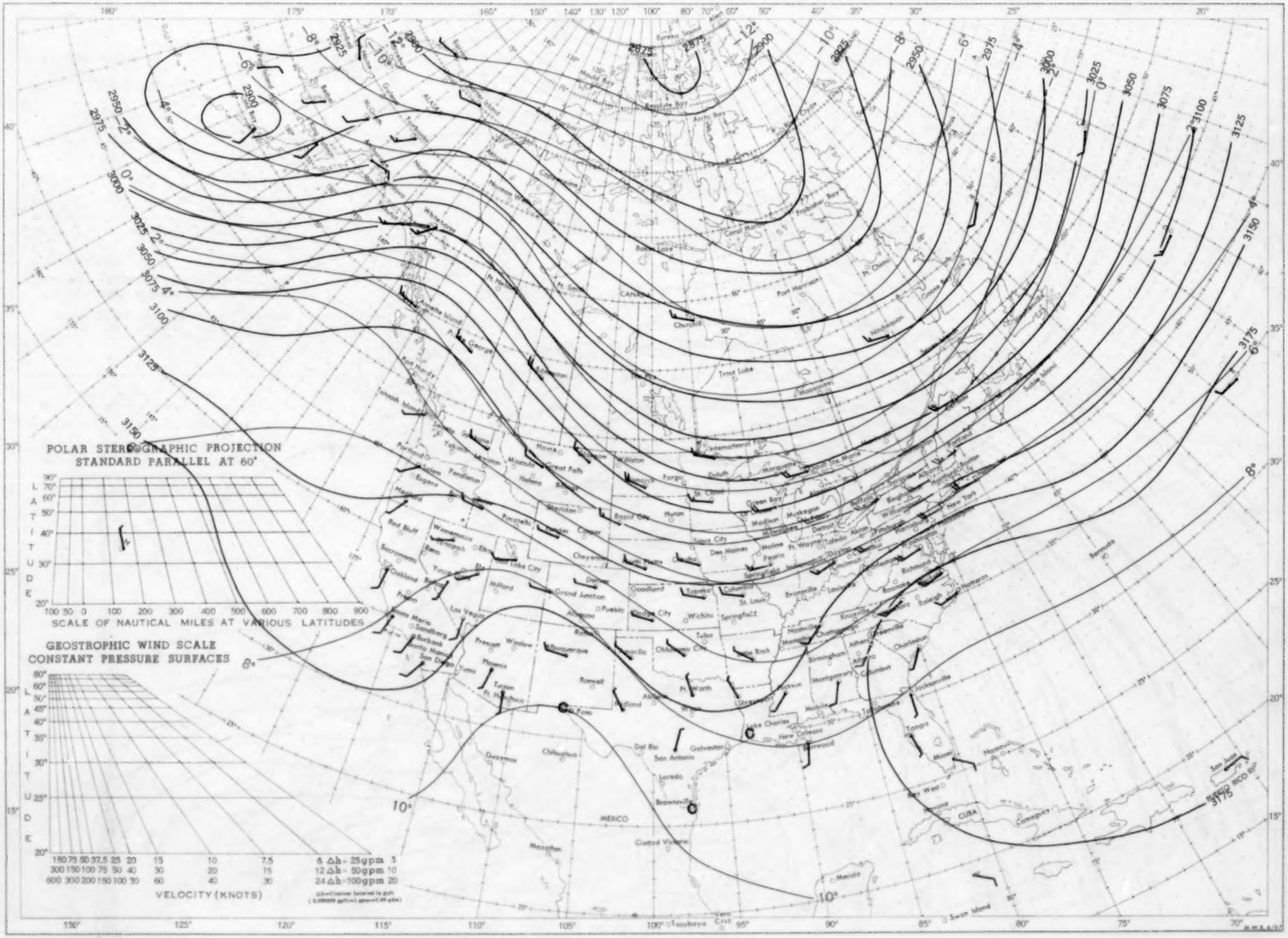
Average sea level pressures are obtained from the averages of the 7:00 a. m. and 7:00 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.



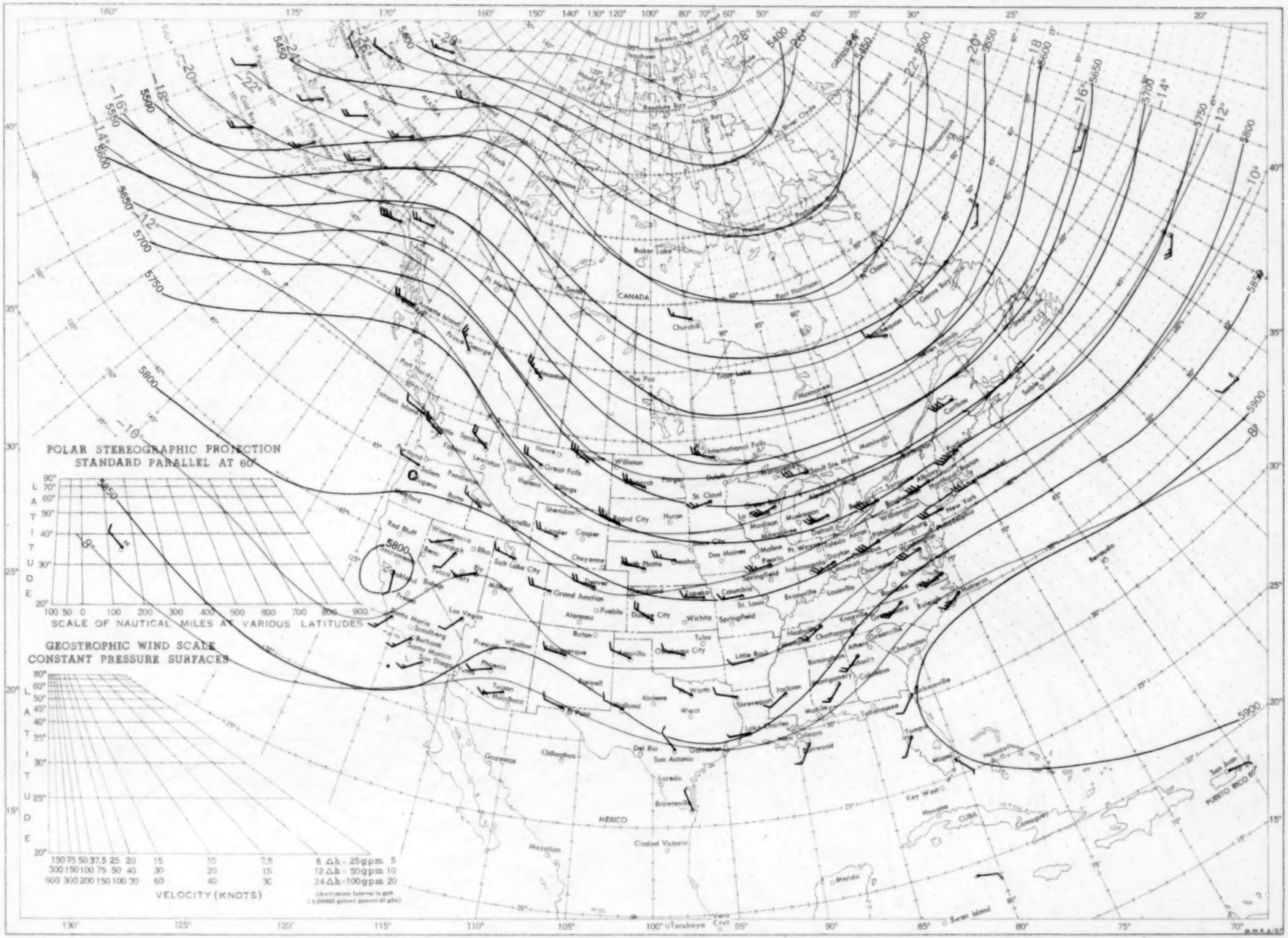
Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. All wind data are based on rawin observations.

Chart XIII. 700-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES
GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES
VELOCITY (KNOTS)
6 Δh = 25 gpm 5
12 Δh = 50 gpm 10
24 Δh = 100 gpm 20

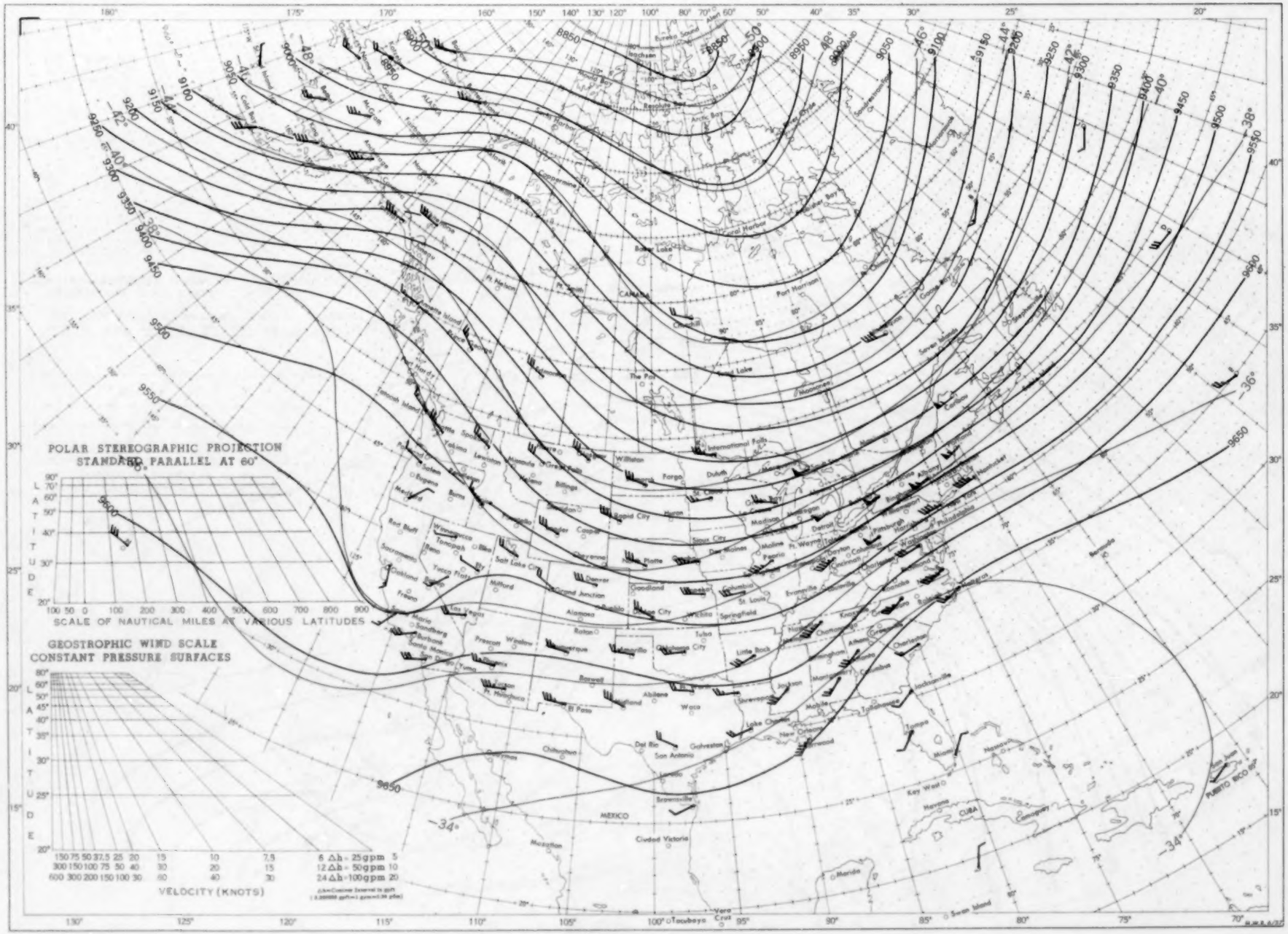
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.



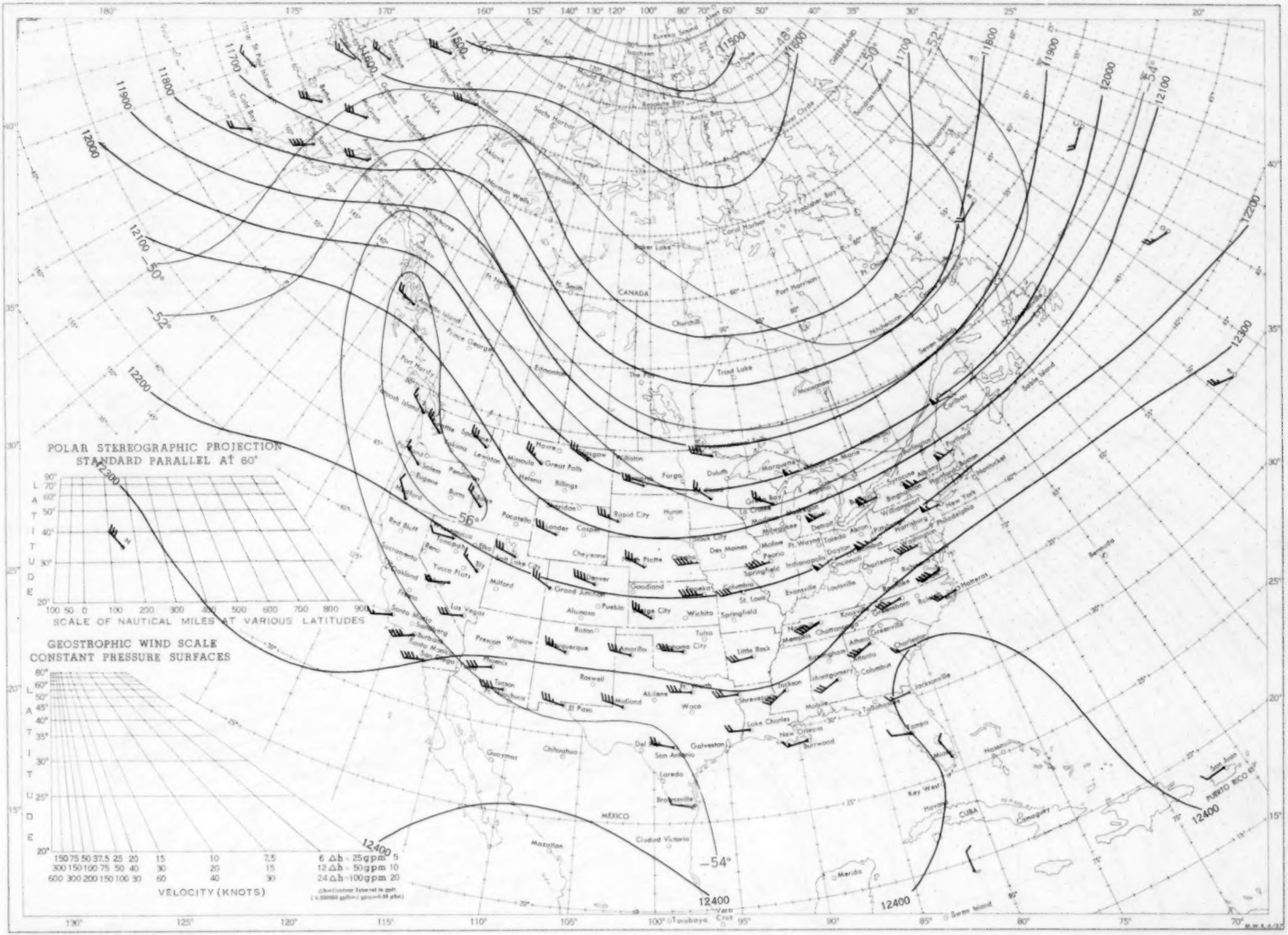
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF NAUTICAL MILES AT VARIOUS LATITUDES
GEOSTROPHIC WIND SCALE
CONSTANT PRESSURE SURFACES
VELOCITY (KNOTS)
6 Δh = 25 gpm
12 Δh = 50 gpm
24 Δh = 100 gpm

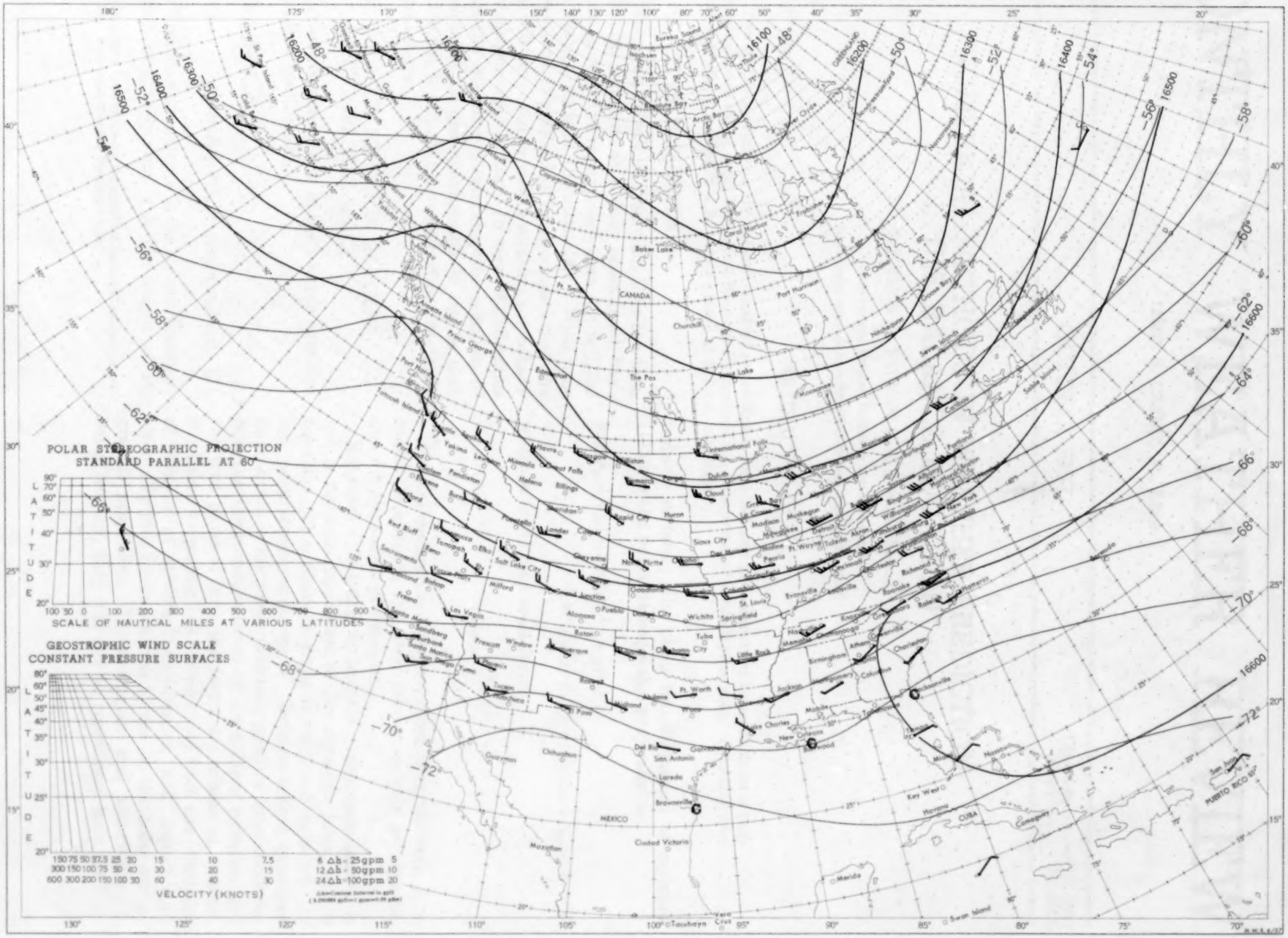
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map.

Chart XVII. 100-mb. Surface, 1200 GMT, September 1957. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map.